THE EFFECT OF DRYING CONDITIONS AND CERTAIN PRE-TREATMENTS ON SEASONING STAIN IN CALIFORNIA REDWOOD*

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California redwood is subject to a chemical stain in the surface zone of the lumber. Most serious stain is found in lumber cut from the outer part of the heartwood in butt logs. Generally, this material has the highest moisture content of the tree and usually is segregated as sinker stock. The content of extractives in this zone is also higher than elsewhere in the tree (1). The stain is associated with migration of extractives during drying as the moisture moves to the surface bringing water soluble extractives with it, which are deposited and concentrated in the zone of evaporation.

Also in drying, sticker marks become apparent as a result of contrasting light colored zone (or stain free zones) under the stickers with comparatively darker stained areas adjacent to the sticker zone. The extractives which would have normally been deposited at the sticker position if free evaporation were possible, have migrated to the zone adjacent to the sticker thus adding to the normal concentration of the extractives in that area as established by Anderson (2).

It has been reported by the California Redwood Association (3) that any condtion which permits the moisture in the wood to dissolve large quantities of extractives before or after drying will lead to an increase in the amount of stain; therefore, low temperatures and humidities, and good circulation are recommended to reduce the stain. In one comparative industrial drying test † between air drying plus kiln drying and kiln drying from the green condition, kiln dried material showed less stain. Also, it has been repored (3) that a low pH content of the wood will accentuate stain and that pH of the wood decreases on exposure to oxygen. Therefore, rapid conversion and sticking of the lumber is recommended.

The present study was undertaken with three related objectives: 1) to determine the effect of drying variables on seasoning stain with a view to recommending optimum drying procedures; 2) to study the extractives, their migration, and behavior in relation to drying variables; and 3) to study the extractive materials from a chemical viewpoint to define their chemical structure and properties.

These studies were made concurrently to gain a more comprehensive understanding of the problem. This paper will be concerned largely with the effect of drying variables and pretreatments on stain occurrence and a second paper dealing more with the chemical implications of the study will be presented in June at the National Meeting of the Forest Products Research Society.

PROCEDURE

This study was done in two series. In the first series, which was exploratory, 4/4 redwood boards were kiln dried under a variety of conditions and concurrently a study was made on techniques of evaluating stain, extractive movement, and extractive components responsible for the stain. All material for the runs was supplied in one shipment. In the second series of the experiment, the techniques developed in the first stage were applied with more precise control of variables.

Series 1

Material. Sinker segregation redwood (1250 bd. ft.) cut from the outer zone of the heartwood of butt logs was ordered from a Eureka sawmill in cant sizes of 6" x 10" cross section in 20 ft. lengths. Specifications called for material to be cut from several freshly felled logs and to be shipped to the Richmond Laboratory without delay. The material arrived at the Laboratory in early March and the last drying run of the series was completed in late July.

On arrival at the Laboratory, the cants were cut into 8 ft. lengths and side and end matching used for all comparative drying studies. According to the procedure, 25 5/4 boards were cut from the cants just prior to each run and planed to 4/4 thickness before use to facilitate shrinkage measurements and sectioning techniques. The remainder of the material was stored in cant form until required.

Drying Conditions. Five kiln runs were then made consecutively and a control pile set out for air drying under cover on the Laboratory grounds. Preliminary examination of the time of stain development indicated that stain development occurred during the period of "free" water movement. It was therefore apparent that this period was the most critical with respect to drying conditions and, consequently, drying conditions for the kiln runs were varied only above 30 per cent moisture content. Drying from 30 per cent moisture content down to a final moisture content of 8 per cent was done uniformly at 160 degrees F. DBT with a 30 degree F. WBD* with conditioning treatment of 180 degrees F. with 10 degrees F. for 15 hours at the conclusion of the drying.

As temperature, humidity, and drying time were considered to be the most important drying variables, drying conditions down to a wood moisture content of 30 per cent were kept constant to simplify the interpretation of the quantitative effects of the variables.

The kiln drying conditions used in the first stage of the run are shown in Table 1.

TABLE I

Drying Conditions Used in Series 1. Conditions to 30 Per Cent

Wood Moisture Content

Kiln Run No.	Dry Bulb Temperature °F	Wet Bulb Depression °F
1	130	4
2	150	5
3	110	15
4	150	15
1A	130	4

*WBD - Wet bulb depression
DBT - Dry bulb temperature

Run No. 1A duplicates Run No. 1 in order to determine the effect of the 5 month storage period. All kiln drying was done in a small experimental drying kiln with air velocities of 450 ft./min. through a 30" wide pile so that the temperature drop would be minimized.

Stain Evaluation. The evaluation of stain was made on the freshly dressed surface of the boards at the conclusion of drying both before and after conditioning. A planing depth of 1/16" was adopted after preliminary tests showed that this depth always fell in the stained zones and because it was similar to trade practice in depth of planing.

After drying, freshly planed samples of the boards were subjected to high humidity (approximately 90 per cent) at 80 degrees F. for 24 hours and re-evaluated.

Evaluation was made by two methods: 1) visual estimation in which the amount of stain and its intensity was given a numerical rating on a five point scale; and 2) reflectance measurement in which a reflectometer measured the reflected light from the surface of the test boards. As the field of reflectance was small, 36 readings were taken on a grid system drawn on the surface of the board. Filters were also used to reduce the effect of board color (as distinct from stain) on the readings.

Extractive Determination Wafers for extract analysis were cut from boards in each kiln run and from the material in the air drying pile before drying commenced, at intervals during drying, at the end of drying, before conditioning, and after conditioning.

The wafers, after having been cut from the board, were cut into slices for determination of extractive migration. The slices were cut 3/32" thick from the surface (surface zone); 3/32" thick adjacent to the surface (intermediate zone), and 6/32" thick in the center of the wafer (central zone). The extractives in each of these 3 zones were then chemically analyzed.

Although it was believed that the initially water soluble components were responsible for the stain, water insoluble components were also determined. Therefore gravimetric analysis was made of cold water soluble extracts and hot alcohol soluble extracts. Extraction with water was done first so that the alcohol extract did not contain water soluble material. Absorption analysis with visible light was also made on the cold water soluble extract and the hot alcohol extract to measure their tinctorial power.

RESULTS AND DISCUSSION OF SERIES 1 TEST.

Stain Susceptibility of Material. The average green moisture content of the cants varied from 176 to 134 per cent indicating that only part of the material could be classified as sinker stock and, in general, would not be expected to stain excessively. Although a portion of the material supplied did stain, the stain was not severe in the first kiln charges dried and the material was considered as moderately stain susceptible. The color of the stain varied from a pale brown to a very dark brown and was most pronounced in the summerwood portion of the growth ring. Stain was more severe on quartersawn boards than flatsawn, and tended to occur in streaks, particularly associated with a high count of growth rings per inch. Contrast in stain was most pronounced at the sticker locations where stain was light or absent under the stickers.

Migration of Extractives During Drying. Although a considerable variation existed in the results of both the gravimetric and spectrophotometric determinations on the extractives, certain general trends were clear. In all the kiln runs, the total content of all extractive fractions tended to increase gradually in the surface zone during drying (see Table 2). The center zone showed a progressive decrease in cold water soluble fractions and their tinctorial power, and an increase in the hot alcohol extractives and their tinctorial power (see Table 3). It is clear that in addition to the migration of the water soluble extractives to the surface zone, a change in the chemical nature of the extractives occurred simultaneously, resulting in their reduced solubility in water.

TABLE 2

Migration and Behavior of Extractive in a 4/4 Redwood Board During Drying in Kiln Run No. 1.

	Average Moisture Content of Board at time of Analysis (per cent)							
	155	130	95	77	55	32	13	7
Surface Zone								
CW %	8.9	11.9	15.1	14.1	14.4	13.3	14.3	14.64
CW vs	.022	.037	.109	.052	.041	.075	—	.063
HA %	6.48	6.33	6.33	5.86	6.71	7.57	9.33	10.27
HA vs	.252	.284	.267	.306	.286	.358	.416	.484
Intermediate Zone								
CW %	9.11	8.51	6.77	8.10	6.99	9.50	9.30	9.30
CW vs	.025	.025	—	.0223	.021	—	.0299	.030
HA %	7.21	6.03	—	—	7.33	6.99	7.31	9.39
HA vs	.208	.282	.234	.234	.298	.299	.294	.361
Central Zone								
CW %	8.58	—	7.49	6.74	6.62	5.80	5.30	4.92
CW vs	.031	.030	.022	.022	.031	.050	—	.027
HA %	7.24	6.24	4.13	4.13	6.14	5.82	9.74	8.17
HA vs	.247	.208	.211	.211	.265	.259	—	.389

CW % — cold water extract
HA % — hot alcohol extract

CW vis — cold water visible spectrum
HA vis — hot alcohol visible spectrum

TABLE 3

Distribution of Extractive in Kiln Dried Redwood

	Surface Zone		Intermediate Zone		Central Zone	
	G.L.	**K.D.**	**G.L.**	**K.D.**	**G.L.**	**K.D.**
	Run No. 1 (130° F. — 4° F. 21 days)					
C.W.%	11.47	14.53	11.60	12.28	11.63	6.40
C.W.vs	.0465	.1342	.0490	.0722	.0556	.0350
H.A.%	7.22	12.73	7.51	8.16	8.85	8.72
H.A.vs	.2732	.7706	.2483	.5413	.2866	.4471
Tot. Ext.	20.92	28.91	21.29	22.04	23.06	16.67
	Run No. 2 (150° F. — 5° F. 16 days)					
C.W.%	11.44	13.58	11.90	11.37	11.77	5.59
C.W.vs	.0515	.0702	.0492	.0346	.0716	.0175
H.A.%	7.70	10.42	7.94	9.11	7.23	10.03
H.A.vs	———	.5075	———	.3670	———	.3688
Tot. Ext.	21.42	26.34	21.87	22.84	21.47	18.60
	Run No. 3 (110° F. — 15° F. 14 days)					
C.W.%	10.52	16.23	11.70	10.09	11.56	7.21
C.W.vs	.0838	.1173	.1036	.0777	.1002	.0582
H.A.%	8.48	8.48	8.31	7.35	8.20	7.81
H.A.vs	.3310	.3305	.3341	.3277	.3064	.3270
Tot. Ext.	21.79	28.62	23.07	20.98	22.07	18.95
	Run No. 4 (150° F. — 15° F 12 days)					
C.W.%	15.58	16.62	12.15	6.56	11.03	4.18
C.W.vs	.1082	.1872	.1347	.0330	.1095	.0309
H.R.%	———	10.95	6.50	8.47	6.47	8.01
H.A.vs.	.2766	.5768	.2718	.3881	.2656	.3130
Tot. Ext.	———	27.57	18.65	15.03	17.50	12.19
	Air Dried Run (78 days)					
C.W.%	11.47	18.33	11.60	13.22	11.63	7.85
C.W.vs	.0466	.1233	.0491	.0871	.0556	.0753
H.A.%	7.20	9.01	7.55	8.46	8.91	8.08
H.A.vs	.2735	.3612	.2484	.3261	.2866	.3693
Tot. Ext.	20.99	29.57	21.30	23.91	23.11	17.11

G.L.—Green Lumber; K.D.—Kiln Dried.
C.W.%—Cold Water Extract; C.W.vs—Cold Water visible spectrum
H.A.%—Hot Alcohol Extract; H.A.vs—Hot Alcohol visible spectrum.

It was also noticed that the lower the temperature of drying, the relatively more cold water soluble material and relatively less hot alcohol soluble material was deposited at the surface (see Table 3). This is to be expected if the temperature of drying converts a part of the water soluble fraction to a water insoluble form.

Effect of Drying Conditions on Stain. The ratings of stain by the two different methods are shown in Table 4.

TABLE 4

Listing of Drying Schedules in Increasing Order of Stain Development

Stain Classification	Visual Observation	Reflectance Measurement
Very Slight	Kiln Run No. 1 Air Drying	Air Drying Kiln Run No. 1
Moderate	Kiln Run No. 2 Kiln Run No. 4 Kiln Run No. 3	Kiln Run No. 3 Kiln Run No. 4 Kiln Run No. 2
Severe	Kiln Run No. 1A	Kiln Run No. 1A

Both systems of rating were in agreement in determining that dried and kiln dried Schedule No. 1 caused the least and Kiln Run No. 1A caused the most stain. The reflectance evaluations indicates a relationship between stain and temperature of drying. The discrepancy between the ratings for Kiln Runs Nos. 2, 3, and 4 is due to two factors. First, the variation in stain between these three runs was slight and second, errors were apparent in the reflectance measurement due to variations in the natural hue of the wood and the effect of widely differing reflectance values of the earlywood and latewood growth rings. It is therefore considered that the visual observation is the more reliable of the two systems.

At the outset, it is apparent that a major factor involved in stain production was the storage time of the material before drying as Kiln Runs Nos. 1. and 1A were the same schedule but carried out at a 5-1/2 month interval. Because of this consequence, it is not possible to state the effect of the drying variables on stain occurrence with any certainty as storage time appears to be a far more critical factor than the actual drying conditions within the range tested. However, the fact that there was little or no difference between the material which was air dried and that which was dried in Kiln Schedule No. 1 indicates that a wide variation in drying temperature and humidity does not substantially affect the stain occurrence, at least for material which is slight to moderately stain susceptible. Further, it is apparent that, if storage time in cant form has been substantial, then kiln drying at any reasonable schedule (having regard to the prevention of other drying defects) will not obviate stain.

With reference to air drying, it should be pointed out that the air drying at the California Laboratory (particularly in a small pile) is substantially faster than that prevailing in the Eureka area. Therefore, it may be expected that under very slow air drying conditions such as may exist in the Northern coastal area of California, an effect similar to long term green storage could be obtained.

In correlating the extractive behavior with stain it is seen that the amount of stain can not be directly correlated with the amount of total extract or with components of the extract within the range of extractives covered. However, as the differences in stain were not particularly marked, except for Run No. 1-A, which was not analyzed, this is not surprising. The indications were that the stain is associated with both the cold water and hot alcohol soluble fractions but that the critical staining material, which was not isolated, may be only a proportion of these extractives.

Effect of Exposure to High Humidity. All surfaced boards show an increase in the intensity of the stain when exposed to high humidity at the conclusion of drying. Also, the extractives on the surface of the boards appeared very hygroscopic and tended to liquify. The change in staining intensity obtained under high humidity is shown in Table 5. The reflectance technique was used for this evaluation as measurements were taken on identical spots before and after exposure to give accurate comparisons.

TABLE 5

Influence of High Humidity on Stain in Sample Boards Dried under Different Conditions

(Listed in order of increasing severity of increased stain)

Kiln Run No. 1A
Kiln Run No. 2
Kiln Run No. 4
Kiln Run No. 3
Kiln Run No. 1
Kiln Run No. Air Drying

It is seen from comparison with Table 4 that the effect of high humidity was generally greatest on those boards which showed the least amount of stain on removal from the kiln and was least on material which showed the most stain after drying. This correlates, therefore, with the temperature of drying, i.e., elevated temperatures during drying reduce the tendency of the material to show increase in stain when exposed to high humidity, and probably with the content of water soluble extractive in the surface zone.

Series 2—

Material and Drying Procedure. In this series, 8 kiln runs and one air drying run were made. In the first 6 runs, the effect of drying variables on stain was studied; and in the last 2 runs, the effect of long term storage of the lumber on stain was examined. In order to control the effect of log cant and cant storage time on stain development, freshly cut cants from recently felled trees (within one month) were shipped to the Laboratory at intervals and dried immediately, 2 runs at a time, under widely differing drying conditions. Exact matching of material was possible within each pair of kiln runs.

For the last 2 runs, cants which had been cut 6 months were used to provide material to evaluate the effect of storage time. Before conversion of the cants into 4/4 boards the outside 1/4" was sawn off around the cant to avoid semi-dry material in the drying runs.

The kiln schedules were a two stage type similar to that used in Series 1 runs, except that drying from 30 per cent moisture content down was done uniformly at 180° F. DBT - 50° F. WBT with one exception. All other drying conditions were similar to those used in Series 1. The schedules used are shown in Table 6.

TABLE 6

Drying Conditions Used in Series 2
To a Wood Moinsture Content of 30 Per Cent

Matching of Material	Kiln Run No.	DBT °F.	WBD °F.
Matched	5	110	20
	6	140	5
Matched	7	110	4
	8	140	40
Matched	*9	110	10
	10	110	10
Matched	11	140	5
	12	110	20

* Drying conditions changed to 140° F. DBT — 40° F. WBT at 30 per cent wood moisture content.

Sticker Stain Studies. In order to determine whether it was possible to reduce the contrast of stain at the sticker location, various porous materials (blotting paper, fibrous insulation) were placed between the sticker and the board surface in selected test runs. In one case blotting paper was fastened to the complete surface of a board in an attempt to obtain deposition of extractives in the blotting paper rather than on the surface zones of the board.

Pretreatments to Prevent Stain Development. Three types of pretreatment were tested as follows:

a) Sodium azide (an enzyme inhibitor) which is proving successful in inhibiting brown stain in sugar pine was applied to selected green boards and boards which had been dried for 1-1/2 days to reduce the moisture content of the surface zone. Treatment was accomplished by dipping the boards in a solution containing 4 lbs. of Bazide plus 10 lbs. of Permatox S per 100 gallons of water.

b) Water repellent preservative solutions (commercial preparations) were applied by dip treatment for 3 minutes to green boards and to boards which had been dried for 1-1/2 days to reduce surface zone moisture content. Although water repellents are not intended for this type of treatment, it was thought that water repellants or similar materials may alter the zone deposition of the extractives.

c) As heat appeared to have an effect on the nature of the extractives, selected boards were subjected to heating prior to drying by two different methods.

Method (i) employed live saturated steam. Under the saturated conditions no appreciable drying took place. The treatments applied were:

225 degrees F. 30 mins.
212 degrees F. 10 mins., 30 mins., 2 hours, 7 hours, 15 hours
180 degrees F. 15 hours

Method (ii) utilized high frequency heating between platens at 212 degrees F. for 4 mins. and 20 mins.

Storage Effects. As each kiln run was constructed, samples were taken and placed in cold room storage. In the last kiln run (No. 12) made, these samples were included to determine the effect of storage on stain development in subsequent drying.

Stain Evaluation and Extractive Determination. Stain was evaluated visually on a 7 point scale as in Series 1. The boards for extract analysis were selected on the basis of high initial moisture content. Extract determinations were made as described in Series 1 at the beginning and end of each run. Extract distribution was also evaluated at the sticker zones where porous stickers were used for comparison with normal sticker zones. Also, extractive evaluations were made on the heat treated material

RESULTS AND DISCUSSION - SERIES 2

Stain Susceptibility of Material. The lumber obtained for this series was inherently much more susceptible to stain than that supplied for Series 1 tests. The green moisture content of the lumber was generally over 200 per cent with a portion as high as 246 per cent, hence the material would be classified as sinker stock. The total extractive in the wood averaged considerably higher than that in Series 1. The total extractive content for green lumber in Series 1 averaged above 20 per cent, rising to 36 per cent maximum compared to an average of approximately 11 per cent for the lumber used in Series 1.

Behavior of Extractives During Drying. The total extractive content for all kiln runs showed an increase of approximately 60 per cent in the outer zone and a decrease of approximately 30 per cent in the inner zone from green to dry. This was mostly due to the approximate doubling of the cold water soluble extracts in the outer zone together with a lesser increase in the hot alcohol extractives. Comparatively slight differences occurred in extractive migration and change in their water solubility within closely matched pairs of runs of widely differing temperature and humidity. There was a slight tendency for a little more cold water soluble extractives and a little less hot alcohol extractives to be deposited in the surface zone in the lower humidity runs. This effect was present at both dry bulb temperatures of 110 degrees F. and 140 degrees F. It may be due to the reduced time of drying compared to the higher humidity runs and consequently to the reduced temperature-time effect on converting water soluble to water insoluble fraction. In iteslf, temperature did not appear to have a marked effect.

The effect of drying temperature after 30 per cent moisture content had been reached (runs 9 and 10) showed that higher final drying temperature reduced the cold water soluble extract and increased the alcohol extract in the surface layers, but the effect was very slight.

It is therefore clear that there was a tendency for both higher drying temperatures and high humidity to slightly reduce the concentration of water soluble extractives and increase the water insoluble extractives in the surface zone. However, the general pattern of extractive migration and proportion of the two extractives found in the surface layers was not substantially altered.

Effect of Drying Conditions on Stain. All boards containing a total extract of 20 per cent or more showed moderate to severe stain under all drying conditions. No discernible difference in stain could be found between closely matched material dried under very different conditions within pairs of kiln runs. Therefore intensity and amount were related more to the total extractive content in the board rather han the drying conditions used. This behavior correlates with the substantial migration of cold water soluble extractives and increase in hot alcohol extractives in the surface layer for all runs. The stain which developed in matched samples dried in kiln runs 5 and 6. However, the intensity of the stain and the general color of the air dried boards were lighter than in the kiln dried material. The stain and color of the board of the air dried material darkened when kiln dried from approximately 20 per cent moisture content to 8 per cent, so that only a slight difference in intensity of stain was apparent between boards which had been air dried then kiln dried, and boards which had been kiln dried from green.

It is clear then that little can be expected in the way of reducing stain by control of temperature and humidity in conventional kilns, at least within the limits which would allow economic operation and not cause other defects in the lumber.

Effect of Stain on Exposure to High Humidity. Differences in the increase of stain were negligible in boards kiln dried by different schedules when subjected to short term high humidity. Although it may be expected that those boards containing the higher content of cold water soluble extractives would show more change, the high content of water soluble extractives in all material no doubt masked the relatively small difference resulting from different drying conditions.

Boards which had been air dried showed a substantial darkening when exposed to high humidity while boards which had been air dried and then kiln dried showed less change, but nevertheless, more change than was shown by the boards kiln dried from the green.

Reduction of Intensity of Sticker Mark. Application of blotter pads 1/4" thick under the stickers considerably reduced contrast in this area resulting in barely visible sticker marks. Although the porous pad absorbed some extractives, some were deposited under the sticker and no substantial build up of the extractives occurred on either side of the sticker as shown by gravimetric extractive analysis. A similar effect was noted with fibrous insulation type sticker. Although there are difficulties in instituting such a procedure on a commerical scale, it does suggest an approach to reduction of sticker stain.

In the board which had been completely covered with 1/4" thick blotting pads stapled to the surface, differential shrinkage between the board and the blotting pad during drying resulted in wrinkling of the pad so that cantact was not uniform. However, on the areas of contact it was apparent that a large proportion of the extractives had moved into the blotting pad resulting in less stain in these areas. It is therefore possible to reduce stain by creating another zone of evaporation of the water in contact with the wood surface.

Effect of Storage. While the results on the effect of cant storage on stain are still being evaluated, boards which had been kept in cold storage for 3 months before kiln drying showed an increase in their intensity of staining as compared to their stain when kiln dried immediately after sawing. This behavior confirms the effect found in Series 1 tests.

Effect of Chemical Treatment. No effect was noted on stain of either the buffered sodium azide plus Permatox S or the water repellent preservatives, whether the lumber was dipped green or surface dried. From the chemical standpoint, it is unlikely that the staining extractive fractions are a result of enzymatic action, and therefore, it is not surprising that the azide was not effective. Further, the stain susceptible green redwood contains very little void space because of the very high moisture content and consequently little chemical applied in a dip treatment would be absorbed by green wood. In surface dry wood, similar difficulties of substantial absorption of chemicals applied by dip treatment also exist because of the relative impermeability of redwood.

Effect of Preheating. A remarkable reduction of stain occurred in boards which were heated before subsequent drying. In the better treatments, the amount of stain was reduced to the extent of being barely visible or non apparent. Similarly, contrast in the sticker areas was not apparent in the heated boards. Presteaming of air dried material before kiln drying did not show any marked effect as might be expected. Presteaming material before air drying and subsequent kiln drying, however, was effective. The least effect of presteaming was observed on green boards which had been kept for 3 months in cold storage drying. The effect of presteaming treatments on reducing or obviating stain appeared to be independent of the kiln drying schedule.

The presteaming schedules which were most effective in reducing stain were 212 degrees F. for 15 hours, 7 hours, and 2 hours and 225 degrees F. for 2 hours. Treatments at 212 degrees F. for 30 mins. and 180 degrees F. for 15 hours, although having a marked effect, were not as effective as those for the longer heating periods.

High frequency heating at 212 degrees F. for 4 mins. was the least effective of the heat treatments, whereas heating by this method for 20 minutes was equivalent in its effect to the steaming treatments at the shorter times.

The chemical analysis of extractives, which was conducted on wood after steaming and after drying, showed the following in comparison to non preheated wood:

a) Preheating green wood tended to reduce the percentage of cold water soluble extractives deposited at the surface layer and to reduce light absorption in the visible spectrum (i.e, reduce tinctorial power) in the hot alcohol soluble and cold water soluble extractives.

b) The effect was more pronounced at the longer heating times.

c) There was some indication that the tinctorial power of the hot alcohol extractives decreased in the outer zone, although the content of hot alcohol extractives increased.

The behavior of the extractives during drying in a typical preheated board in comparison to that in a matched unsteamed board is shown in Table 7.

TABLE 7

Effect of Preheating at 212° F. for 7 hours on Extract Behavior in Surface Zones Before and After Kiln Drying

	Green Control	Green After Steaming	Dried Control No Preheat	Preheated Dried
CW%	9.51	9.94	17.86	15.15
CWvs	.0206	.0122	.0569	.0237
HA %	7.97	7.94	10.94	8.46
HA vs	.3639	.4191	.3655	.1857
Total extract %	17.48	17.88	28.80	23.61

Although the cold wated soluble extractives content in the surface zones of preheated boards was considerably reduced at the end of drying compared to that in boards which were not heat treated, the total cold water soluble extractives and the total extractives exceeded that in untreated boards in other parts of the study which did show substantial stain. In this connection the total extractives and cold water extractives in one of the boards selected for heat treatment was the highest (ie., 33.6 per cent and 18.2 per cent respectively) of any board analyzed during the complete investigation. Material from this board steamed for 7 hours at 212 degrees F. did not show any substantial stain but when dried without preheating, the stain was as severe as any found in the series.

It is apparent that the preheat treatment affected some components of the hot alcohol extractives and probably some of the cold water extractives which are primarily responsible for the tinctorial power of the extractives. Work is continuing to isolate these fractions and determine their sensitivity to heat.

Exposure af the presteamed and dried specimens to high humidity resulted in very little or no increase in the amount of stain. In some cases a very pale brown color was observed on the surface of the samples. In no case did any preheated board show as much stain on exposure to high humidity as the lightest staining boards which contained less than 15 per cent of extractives.

Examination of cross section cut from presteamed and dried boards and then exposed to high humidity showed that extractives were present in surface zone of the sections and were somewhat hygroscopic as expected from the chemical analysis. However, the color of the hygroscopic extractive was very pale amber throughout the full depth of its occurrence in contrast with very dark brown color of the extractives which occurred in non-presteamed sections. This behavior indicates the possibility of a specific effect of heat on the fractions within the extractives which are responsible for staining power as distinct from the effect of the reduced amount of extractives in the surface zone.

Although no substantial staining of the preheated boards occurred on exposure to high humidity, it is yet too early to say whether stain would eventually develop under conditions of service, e.g., as unpainted siding. Weatherometer and exposure tests are planned to evaluate the permanence of the stain reduction together with more intensive chemical investigations.

Although yet to be fully evaluated, preheating appears to be a promising method of reducing or obviating stain. The cost of an operation on higher qualities of sinker stock segregation is reasonable, control is not difficult using saturated steam at atmospheric pressure, and the duration of steaming necessary is of practical length. In this connection, it is not advisable that the duration of steaming be extended beyond 6 hours because of increased tendency of the steamed material to collapse during subsequent drying.

CONCLUSIONS

1. Chemical stain in redwood occurred under all drying conditions used in this study. The intensity and extent of stain was affected most by the total extractive content of the green board which was also associated with the green moisture content of the lumber, next by the length of storage of the green cants or lumber, and least by the actual drying conditions.

2. The period of green cant (or lumber) storage strongly affects the intensity of stain which develops in subesqent drying. A green cant storage time of 5-1/2 months resulted in severe stain development in material which contained only moderate amounts of extractives and which showed only slight stain when dried within a week after sawing.

It is believed that slow air drying conditions would result in similar increase of staining intensity or subsequent drying.

The storage effect on stain production could be expected to be more pronounced on material which contains marginal amounts of extractives, as material with a high content of extractives will stain in any case.

3. The depth from the board surface of the stained zone and its thickness were not measurably affected by the drying schedules used within the limits of the thickness of the sections evaluated.

4. Variation of drying method or drying schedule within the limits of good drying procedure does not provide a means of controlling stain in air or kiln drying.

The extent and intensity of stain developed in the material during drying was only partially affected by the drying conditions. Air drying or kiln drying at low temperatures and low humidities tended to slightly reduce the intensity of staining when examined immediately after drying. This effect was more pronounced on material with marginal total amounts of extractives. In material with medium and high content of extractives, although the air dried material showed least intense stain immediately after drying differences were not apparent between different kiln drying conditions. This behavior was correlated with a trend to the deposition in the surface zone of more water soluble and less water insoluble extractives under low temperature combined with low relative humidity drying conditions indicating a temperature-time dependency on the tinctorial power of the staining components.

5. The extractives deposited in the surface layer were hygroscopic. Stained boards after drying were found to be sensitive to high humidity with respect to darkening of the stain and accentuation of sticker marks. The increase in stain which developed was essentially permanent and persisted

after subsequent redrying. The extent of this effect varied with the drying conditions used.

Boards dried under conditions which resulted in the least intensive stain immediately at the conclusion of drying, showed the greatest amount of increase in intensity of stain when exposed to high humidity. Such differences of stain which did result from drying method or schedule were reduced after exposure of the board to high humidity, the net effect being that drying conditions only partially alter the final staining intensity. Indications from chemical analysis of extractives showed that material containing the highest content of water soluble material in the surface zone was affected most by subsequent high humidity.

6. Contrast in color at sticker area in stain susceptible redwood can be minimized by use of porous material between sticker and lumber so moisture can move from surface zone under sticker without impedence.

7. Heat treatment of the lumber prior to both air and kiln drying markedly reduced the amount of stain occurring in subsequent drying. The treatment was effective for all kiln schedules tried and for air drying. Further, the heat treated material did not show substantial darkening when exposed to short term high humidity after drying which indicates that staining of the lumber during outdoor exposure may be considerably reduced. Weatherometer and long term exposure tests of the heat treated material are necessary to determine the permanence of the effect. There was some indication that heat treatment was less effective on green material which had been kept in storage for 3 months before heating and drying. These effects are being investigated further.

Chemical analysis of heat treated material showed that although the treatment caused some reduction in the deposition of water soluble extractives in the surface zone, in subsequent drying the main effect was a reduction in the tinctorial power of components in the water soluble and alcohol soluble extractives. Further investigation of the nature of these tinctorial materials is proceeding.

Although further work is necessary to evaluate the limitations and potentialities of the method, heat treatment of stain susceptible redwood shows promise of being an effective means of reducing stain and is believed to be a commercially feasible operation.

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