**Colour Measurement Of Treated And Air-Dried Wood**

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The measurement of colour is fraught with difficulty unless use is made of a quantitative colour guide such as the Munsell or L* a* b* system. One problem we have frequently observed in attempting to document a colour is that the reference tabs found in the Munsell charts are often faded. The use of a Minolta Chroma Meter provides an easy way around the problem. After calibration to CIE (Commission Internationale de l'Eclairage 1931) standard C (6774K) the wood samples were measured in an indented zone marked by a 5mm diameter eyelet. In order to assess the nearness of colour of the treated to the air-dried samples, the ΔE*ab values were calculated according to the equation.

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{½}$$

This assumes that colour space is Euclidean (three dimensional) and ΔE*ab is the straight-line distance between co-ordinates of the sample and the standard. L* is the lightness variable and a* is the green (¯ve) to red (⁺ve) chromaticity co-ordinate while b* is the blue (¯ve) to yellow (⁺ve) co-ordinate. A diagram illustrating the three dimensional reality of the L* a* b* system is shown in figure 1.

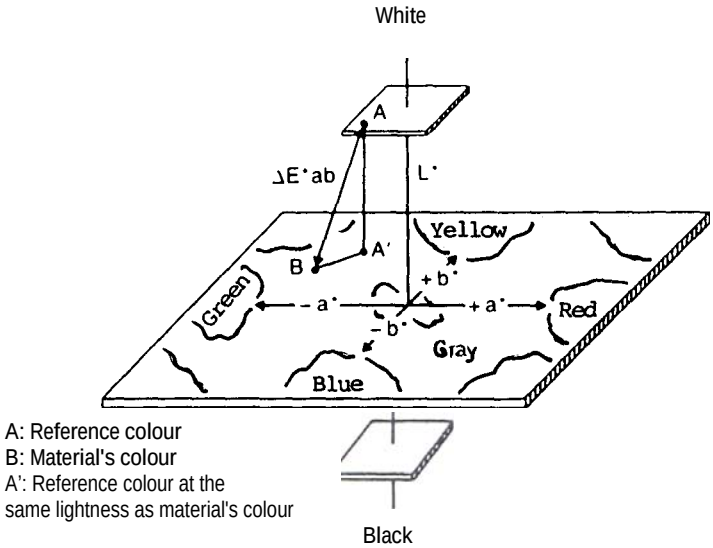


Figure 1: Schematic representation of the L* a* b* system of colour measurement

In order to assess the colour change involved in a particular treatment programme it was essential to tabulate the data according to the same samples of timber treated by the different methods. The detailed L* a* b* values for the Norwegian spruce and the Western Australian jarrah are listed in Tables I and II respectively along with the ΔE*ab values. The chromameter had not been previously used for quantitative measurement of colour on archaeological wood samples and so we were naturally concerned about the reproducibility of the individual L* a* b* values even over a given area of timber. The values for the Norwegian spruce show the standard deviation of ten measurements and the ΔE*ab associated with the S.D. is approximately 0.5 thus any ΔE*ab value within 0.5 of another would be regarded as being the same. It should be noted that the L* a* b* values for the freeze-dried jarrah were different to those of the air-dried reference (see Table II) with a colour difference of 4.2 units. This value may be a reflection of a difference in the micromorphology of the surfaces of the two samples. Freeze-drying the reference sample (without PEG pre-treatment) will induce less stress and hence less distortion and will result in a more "reflective" surface. This is seen in the freeze-dried sample having a higher lightness value.

**Colour Changes of Norwegian and Canadian Spruce**

The results shown in Table I include the comments made by the conference members on the acceptability of the colour (see Grattan's summary). Given that Sawada's group bleach their timbers, to reveal any black lettering, it is not surprising that their sample was the lightest. However, it should be noted that the colour difference is within the range of the "freeze-drying" effect on ΔE*ab values of 4.2, i.e., the Sawada timber has the identical colour to the reference material. The observers appear to have built in a 'normal' value for the colour of PEG treated spruce of about 13 units. The Grenoble sample treated by radiation polymerization had a higher b* value (more yellow) than the air-dried reference and so appeared to be light whereas the Austrian freeze-dried (15% PEG 400) that was given a normal rating had a lower a* value (less red) than the

air-dried reference. The viewers appear to have a greater sensitivity to changes in the yellow-blue chromaticity variable than in the red-green range.

The darkest samples (RIM PEG and TROND PEG) were both treated with PEG 4000 - the RIM PEG sample had used iso-propanol as solvent, which enhanced the redness of the wood compared with the reference material. It should also be noted that the air-dried TROND PEG had used 90% PEG 4000 whereas the freeze-dried RIM PEG had used 50% PEG 4000 in the impregnation bath. Higher concentrations of PEG do tend to make the wood darker even when using low molecular weights. For example, the ratio of PEG 400 concentrations for ARCS FD to TROND FD and CTBGE FD was 0.75 whilst the ratios of the $\Delta E^*ab$ values were 0.75 and 0.71 respective. For the CCI FD2 using 50% PEG 1450 and the WAMM5 using 70% PEG 1500 the ratio of impregnant is 0.71 whilst the ratios of $\Delta E^*ab$ values is 0.79. The colour differences of the twinned PEG treatments is more difficult to assess, but it can be noted that the EHFD treatment using 10% PEG 400 with 15% PEG 4000 gave a smaller colour difference than the CCI FD1 treatment which used 15% PEG 400 and 15% PEG 3350, i.e. the greater the PEG concentration the darker is the treated wood at any given molecular weight of impregnant.

By way of comparison the $\Delta E^*ab$ values of the Canadian spruce are also listed. The NARA PEG had the highest colour difference and this is primarily due to the bleaching which gave it an L* value of 61.74 compared with the air-dried standard of 29.36. The colour of the Canadian spruce does not seem to be as dependent as the Norwegian spruce on the molecular weight or the concentration of the PEG. This is probably due to the fact that as it is less degraded there is less chance for PEG to penetrate. Nine of the treatment programmes (CTBGE RP, EHFD, ARCS FD, CCI FD1, CCI FD2, ROSIN, HOFF PEG, TROND FD and CTBGE FD) gave colour difference that were within 5 of the Norwegian spruce so the treatments can be said to be reproducible. The mean value of $\Delta E^*ab$ for all but the bleached sample was 13.45±3.12 which shows how little the effect of M.W. and concentration of PEG was on this slightly degraded timber.

**Colour Changes of Western Australian Jarrah**

The effect of freeze-drying on untreated reference samples has been previously discussed in terms of the different micromorphology or surface roughness. Inspection of the colour differences of the Jarrah samples shows that compared with the $\Delta E^*ab$ "freeze-drying factor" of 4.2 and the error associated with measurements of the same sample (±0.5) any colour differences within the range of zero to 4.7 could be regarded as normal. Three samples fell within this range (WAMM PEG - 20% PEG 1500, CCI FD2 - 50% PEG 1450 and CCI FDI - 15% PEG 400/15% PEG 3350) and the participants described them as normal. Although the colour difference of the acetone-rosin treated sample was only slightly greater at 5.0 the delegates found it to be 'dark' - perhaps the "darkness" was due to the lower a* value, i.e., it was less red than the reference material. Acetone is known to readily extract red-coloured materials from jarrah and so the six-month impregnation in acetone may have left the wood surface depleted in these pigments. The other acetone-based treatment (the Grenoble radiation cured resin) appeared to be normal or natural with a colour difference value of $\Delta E^*ab$ 5.9. It soaked in acetone for roughly half the time of the rosin sample. Comparison of the L* a* b* values of these two wood samples shows that the Grenoble sample has more red and more yellow in it and so appears to be much lighter than the sample treated by rosin whereas the lightness measures are essentially identical.

The jarrah samples treated by 10% diethylene glycol (HOFF PEG), 15% PEG 400 (ARCS FD) and the twinned 10% 400/15% 4000 (EHFD) all gave a 'normal' colour with colour differences ranging from 6.0 to 8.3 relative to the air-dried reference. The lightness (L*) values of these samples were all slightly higher than the reference as were the chromaticity values of a* and b*. However, when we looked at the TROND PEG (90% 4000 air-dried) its $\Delta E^*ab$ value was only slightly higher at 8.5, but it was rated as being black to very dark. Inspection of the L* a* b* readings provides an immediate reason why it appeared to be so dark, the a* reading had gone from moderately positive 'red' values into the green region and the b* value had fallen to a less yellow - more blue reading. The CTBGE FD and TROND ED which had both used 20% PEG 400 had the same colour differences. The RIM PEG had a larger $\Delta E^*ab$ value which was due to greater b* values (more yellow) and higher L* - perhaps the iso-propanol had helped extract some of the oxidized and darkened colouring matter and largely overcome the darkening normally associated with PEG 4000. The bleached NARA PEG (60% PEG 4000 in t-butanol) had the greatest colour difference owing to the high lightness (L*) reading and elevated b* values. It is interesting to note that seasoned non-waterlogged Jarrah has a b* chromaticity value very similar to both the RIM PEG and the NARA PEG samples.

In summary we can say that essentially all the treatments of jarrah were successful in producing an end product of acceptable colour and that when choosing a treatment for a highly coloured wood due consideration should be given to the effects of the extracting powers of organic solvents.

**Comparative Colour Response of Oak Wood**

Amongst the wood samples presented for study there were three samples of oak with various degrees of degradation. They were the slightly degraded-*Day Dawn* (1886) material, the logs and wedges from a fourteenth century Dutch vessel that was moderately degraded and the extensively degraded oak from the Somerset levels dating back to 3200 B.C. A summary of the colour differences ($\Delta E^*ab$) of the treated material to the air-dried reference samples is shown in Table III where we see that the colour of the *Day Dawn* oak does not respond in any systematic way to the concentration or the molecular weight of the PEG. The colour of the first five samples all lie within the range of $\Delta E^*ab \leq 10$ and a difference of 28% PEG 4000 in the treatment regimes of RIM PEG and HOFF PEG makes little difference to the colour which contrasts with the effects observed in the Norwegian spruce wood (see Table I). For the De Jong oak, ten out of the thirteen samples all fall within the $\Delta E^*ab \leq 10$ range and again the samples do not appear to exhibit any systematic colour response with PEG molecular weight.

**Treatment of Chestnut**

Many workers in the programme had difficulty gaining a good result with the moderately to extensively degraded timber that had came from a site in Japan and was dated in the range 100 BC to 100 AD. The ΔE*ab values for the treated woods are listed in Table IV along with the individual L* a* b* values. In general the higher concentrations of higher molecular weight PEG's gave a darker treated wood sample with lightness (L*) values half that of the air-dried reference. It was noted by the participants that the EHFD sample was the best of all in terms of overall effectiveness of treatment and apart from the bleached NARA PEG sample it is also closest in colour to the air-dried reference material.

**Summary**

In conclusion we have shown that the use of a chromameter is a valuable adjunct to the conservator who is trying to determine what is the most effective method of treatment of archaeological waterlogged timber and that it provides an unbiased assessment of colour changes.

Table I

Norwegian Spruce (TROND A-23)

| | | | L* | a* | b* | |
|---|---|---|---|---|---|---|
| Air-dried reference+ | | | 57.10 | 3.11 | 17.89 | Canadian |
| | | | (±1:0.26) | (±1:0.24) | (±1:0.34) | Spruce |
| Treatment | Subjective Colour | ΔE*ab | | | | ΔE*ab |
| NARA PEG | light | 3.5 | 53.73 | 2.72 | 18.70 | 34.0 |
| CTBGE RP | light | 10.7 | 46.79 | 4.15 | 20.52 | 12.4 |
| ARCS FD | normal | 13.5 | 44.30 | 1.40 | 13.80 | 18.5 |
| HOFFPEG | slightly dark | 13.7 | 43.72 | 2.15 | 15.21 | 12.2 |
| EHFD | slightly dark | 13.8 | 44.80 | 3.40 | 11.7 | 13.9 |
| CCl FD1 | little dark | 14.8 | 43.11 | 1.51 | 13.27 | 10.6 |
| CCl FD2 | little dark | 15.8 | 42.03 | 3.14 | 13.13 | 17.3 |
| ROSIN | dark | 15.8 | 41.26 | 3.37 | 17.93 | 14.9 |
| TROND FD | dark | 18.0 | 39.14 | 4.48 | 18.05 | 14.4 |
| CTBGE FD | light | 19.0 | 38.46 | 4.14 | 14.18 | 16.0 |
| WAMM PEG | slightly dark | 20.1 | 37.97 | 2.59 | 11. 70 | 12.8 |
| RIM PEG | light | 21.8 | 38.39 | 5.02 | 15.95 | 8.0 |
| TROND PEG | very dark | 24.9 | 33.0 | 2.0 | 11.7 | 11.4 |
| | | | | red ↑ | yellow ↑ | |
| | | | | green ↓ | blue ↓ | |

+Based on ten separate readings, ≠ΔE*ab values have a typical error of 0.5
based on the standard deviation of repeated measurements over the same sample area.

Table II

Jarrah Sample (WAMM LJ)

| | | | L* | a* | b* |
|---|---|---|---|---|---|
| Air-dried reference sample | | | 26.75 | 3.44 | 9.29 |
| Freeze-dried reference sample | | | 30.86 | 3.32 | 8.54 |
| Treatment | Subjective Colour | ΔE*ab | | | |
| WAMM PEG | normal | 3.4 | 29.84 | 3.68 | 7.89 |
| CCI FD2 | normal | 4.2 | 30.86 | 4.08 | 8.48 |
| CCI FD1 | normal | 4.5 | 28.85 | 1.42 | 5.90 |
| ROSIN | dark | 5.0 | 31. 55 | 2.02 | 8.97 |
| CTBGE RP | normal | 5.9 | 31.86 | 5.51 | 11.79 |
| HOFF PEG | natural, little brown | 6.0 | 32.1 | 5.7 | 10.9 |
| ARCS FD | natural | 7.3 | 32.57 | 6.92 | 11.89 |
| EHFD | normal | 8.3 | 34.4 | 6.0 | 11. 3 |
| TROND PEG | black, very dark | 8.5 | 28.67 | -0.61 | 2.05 |
| CTBGE FD | natural | 10.0 | 36. 32 | 4.32 | 12.01 |
| TROND FD | natural, s1. lt. grey | 10.4 | 36.9 | 5.5 | 9.8 |
| RIM PEG* | light, s1. brown | 12.9 | 38.14 | 5.33 | 14.96 |
| NARA PEG | bleached, very light | 25.5 | 50.4 | 5.56 | 18.64 |
| KILN DRIED | | 12.6 | 32.4 | 12.10 | 16.43 |
| | | | | Red ↑ | Yellow ↑ |
| | | | | Green ↓ | Blue ↓ |

≠ Used 10% diethylene glycol

* Used PEG 4000 in isopropanol

Table III

Colour differences of oak wood samples relative to air-dried material

| *Day Dawn* Oak ΔE* | De Jong oak ΔE* |
|---|---|
| 3.5 TROND PEG | 2.9 TROND FD |
| 4.5 ROSIN | 4.4 RIM PEG |
| 6.3 RIM PEG | 4.8 HOFF PEG |
| 7.1 HOFF PEG | 5.1 CTBGE RP |
| 8.0 CTBGE FD | 5.8 ROSIN |
| 12.3 CCI FDl | 6.0 CCI FD2 |
| 17.0 EHFD | 6.2 EHFD |
| 17.3 ARCS FD | 8.3 ARCS FD |
| 17.8 CCI FD2 | 9.5 TROND PEG |
| 19. 5 TROND FD | 9.7 CTBGE FD |
| 19.6 NARA PEG | 14.2 WAMM PEG |
| 27.3 CTBGE RP | 15.4 CCI FD1 |
| | 23.3 NARA PEG |

≠ WAMM PEG - sample not treated.

Table IV

Colour differences for Japanese chestnut (castanea crenata)

| NARA CHESTNUT | L* | a* | b* | Treatment |
|---|---|---|---|---|
| ∆.E* | 46.12 | 6.20 | 18.84 | air-drying |
| 4.8 NARA PEG | 49.13 | 2.41 | 18.62 | 60% 4000 + bleach |
| 6.6 EHFD | 42.06 | 4.13 | 14.06 | 10% 400 + 15% 4000 |
| 10.9 CTBGE RP | 42.29 | 1.03 | 9.65 | 120 days acetone |
| 12.2 CTBGE FD | 40.91 | 1.66 | 8.80 | 10% 400 + 40% 4000 |
| 20.0 TROND FD | 33.0 | 0.7 | 4.8 | 20% 400 |
| 20.3 CCI FD1 | 31.2 | 0.6 | 6.3 | 15% 400 + 15% 3350 |
| 22.3 ARCS FD | 29.42 | -1.25 | 6.02 | 15% 400 + resins |
| 23.0 ROSIN | 27.79 | 0.41 | 6.29 | 227 days acetone |
| 23.5 RIM PEG | 28.12 | -0.40 | 5.23 | 45% 4000 |
| 24.8 WAMM PEG | 27.74 | 0.01 | 3.47 | 70% 1500 |
| 29.0 CCI FD2 | 23.17 | -0.41 | 2.44 | 50% 1450 |
| 29.3 TROND PEG | 23.26 | -0. 77 | 1.98 | 90% 4000 |
| 33.3 HOFF PEG | 19.37 | -1.09 | 0.49 | 70% 3000 |
| | | red ↑ | Yellow ↑ | |
| | | Green ↓ | blue ↓ | |