# THE FINISH PROBLEM: METALLIC DRIERS AS SURFACE-REFERRED PARAMAGNETIC RECONTAMINATION OF NEUTRALITY-GRADED TIMBER

# The Finish Problem: Metallic Driers as Surface-Referred Paramagnetic Recontamination of Neutrality-Graded Timber

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Journal of Equatorial Audio Science, 2026.

**Abstract**

*A companion study established a neutrality grade for structural timber, fixed on residual paramagnetic content and reported as combined iron-plus-manganese mass fraction against a diamagnetic baseline. That grade is a property of the raw billet. This paper addresses what happens to it when the billet is finished. Nearly every oil, varnish, and lacquer used on wood is an oxidative-cure coating, hardened not by evaporation but by metal-catalysed autoxidative crosslinking of a drying oil, and the catalyst is a paramagnetic transition metal -- most often cobalt or manganese -- deposited as a carboxylate salt at a fraction of a percent of metal in the wet film. Because the film sits on the outer surface, the catalyst is deposited precisely where the support contacts the cable. We measured surface-referred volume magnetic susceptibility on 5N teak coupons before and after six finish treatments (raw control, pure tung oil with no drier, boiled linseed with Co octoate, alkyd spar varnish with Co + Mn + Zr, water-based acrylic, and a hardwax oil) by vibrating-sample and SQUID magnetometry, with glow-discharge depth profiling to locate the metal. The oxidative-cure finishes raised the top-50 micrometre susceptibility from the diamagnetic baseline near chi_v = -6 x 10^-6 to net-positive values, reclassifying every catalysed coupon from 5N to below 4N; the metal was confined to the top 50 to 100 micrometres in every case. The recent cobalt-free drier trend (Mn, Fe, and vanadium replacements) removes a toxicology problem but not a magnetic one, since the substitutes are themselves paramagnetic. We conclude that the only finish that preserves a neutrality grade is no finish, and that elemental surface patina -- oxidation of the wood carbon skeleton, which adds no metal -- is the sole cosmetic ageing path compatible with the grade.*

## 1. INTRODUCTION

A neutrality-graded billet earns its grade by measurement: a ferrous-inclusion scan, a bulk susceptibility determination, and a trace-metal assay agree that the wood carries no more than a specified parts-per-million of iron plus manganese, and that its net volume susceptibility remains diamagnetic. Equatorial plantation teak reaches 5N (Fe + Mn <= 10 ppm) as delivered and 6N under single-billet selection. The grade is real, it is certified per unit, and it is entirely a property of the wood as it leaves the mill.

The flagship study (Bosque, Ferro, Park & Tanaka, 2026) noted, in a single closing section, that finishing the wood destroys the grade, and reported one before-and-after measurement on a boiled-linseed coupon to make the point. That observation deserves more than a paragraph. The claim is counterintuitive: a finish is understood by every woodworker as protection, and the idea that a protective coat is the most magnetically destructive thing that can be done to a support material runs against a century of shop practice. If the claim is to carry the weight of a product decision -- supplying supports unfinished, against every customer expectation of a premium wooden object -- it needs to be established quantitatively, across finish chemistries, with the contaminating metal located in depth.

That is the purpose of this paper. We treat the finish not as a surface aesthetic but as a thin, deliberately deposited layer of catalyst metal, and we ask exactly how much paramagnetic mass it places, and where. The answer is unfavourable to finishing in general and fatal to the entire class of oxidative-cure oils and varnishes that dominate fine woodwork, for a reason that has nothing to do with the wood and everything to do with the chemistry that makes the film harden.

## 2. DRIER CHEMISTRY AND METAL LOADINGS

A drying oil -- linseed, tung, and their alkyd derivatives -- hardens by autoxidation: atmospheric oxygen abstracts hydrogen from the bis-allylic positions of the unsaturated fatty-acid chains, forming hydroperoxides that decompose into radicals and crosslink the oil into a solid film. Left to itself this reaction is slow, taking weeks. It is accelerated by driers, also called siccatives: transition-metal carboxylates that catalyse both the peroxide-forming and the peroxide-decomposing steps through a redox cycle between two oxidation states. The classical primary drier is cobalt, cycling between Co(II) and Co(III); manganese (Mn(II)/Mn(III)) behaves similarly. These are the through-drier and surface-drier metals. Zirconium, calcium, and zinc are added as secondary or auxiliary driers -- they do not catalyse the redox step but coordinate the film, improve through-cure, and prevent the surface skinning that pure cobalt causes.

The metal is delivered as a salt of a long-chain organic acid -- historically naphthenic acid (naphthenates), now more commonly 2-ethylhexanoic acid (octoates) -- chosen for solubility in the oil, not for any property of the metal ion beyond its redox chemistry. The salt is sold by its metal content: a "6 percent cobalt" naphthenate is 6 percent cobalt by mass of the liquid drier. In a finished coating the primary-drier metal is typically dosed at 0.02 to 0.1 percent of metal relative to the oil solids, with cobalt at the low end of that band because of its potency and manganese somewhat higher.

These fractions sound negligible, and per unit mass of finish they are. The problem is areal density, not concentration. A single brushed coat of an oil finish deposits on the order of 20 to 40 g of solids per square metre; at 0.05 percent cobalt that is 10 to 20 mg

of cobalt per square metre of surface. A 5N teak billet of 10 ppm Fe + Mn contains, in a representative 200 x 60 x 45 mm block of density 650 kg/m^3, roughly 35 micrograms of graded contaminant metal in its entire volume. The finish on the top face alone deposits several hundred micrograms of paramagnetic metal -- an order of magnitude more contaminant than the whole billet was permitted to contain, placed in a layer microns thick on the surface the cable rests against. The grade was defined to control paramagnetic parts per million; the finish defeats it not by a few percent but by a factor.

## 3. EXPERIMENT: SURFACE-REFERRED SUSCEPTIBILITY BEFORE AND AFTER FINISH

We prepared 36 coupons (60 x 60 x 8 mm) from a single 5N equatorial teak billet, ICP-MS-verified at 7 ppm Fe + Mn, so that all coupons shared one substrate and any post-finish difference is attributable to the coating alone. Coupons were assigned in groups of six to six treatments: (A) raw unfinished control; (B) pure tung oil, drier-free, cured 21 days; (C) boiled linseed oil with cobalt octoate (0.05 percent Co); (D) alkyd spar varnish with a Co + Mn + Zr package (0.04 percent Co, 0.06 percent Mn, 0.20 percent Zr); (E) a water-based acrylic dispersion (no oxidative drier); and (F) a commercial hardwax oil (linseed and carnauba, cobalt-catalysed). All film-forming treatments were applied at two coats to a controlled 30 g/m^2 per coat and cured to handling hardness.

Because the contamination is a surface layer and the coupon is a bulk object, a whole-sample susceptibility measurement dilutes the signal across 8 mm of diamagnetic wood and understates it. We therefore report surface-referred susceptibility two ways. First, whole-coupon net volume susceptibility by vibrating-sample magnetometer (Lake Shore 8600, 300 K), which captures the integrated change. Second, a surface-layer figure obtained by measuring a 200 micrometre face-parallel slice microtomed from the finished surface and remounted, measured on a SQUID magnetometer (Quantum Design MPMS3) for the sensitivity the thin slice demands. The surface-referred value is the quantity that matters, because it is the wood the cable actually touches.

The results are unambiguous. The raw control (A) held the diamagnetic baseline, whole-coupon chi_v = -5.9 x 10^-6, surface slice -6.1 x 10^-6. The drier-free treatments (B, pure tung; E, acrylic) were statistically indistinguishable from the control at both scales -- permittivity aside, they add no paramagnetic metal and do not move the grade. The three catalysed oxidative-cure finishes (C, D, F) all drove the surface slice net-positive: boiled linseed to +2.3 x 10^-6, hardwax oil to +1.9 x 10^-6, and the Co + Mn + Zr spar varnish furthest, to +4.8 x 10^-6. Referred to the surface layer the cable contacts, every catalysed coupon crossed from diamagnetic to paramagnetic and reclassified from 5N to below 4N. Whole-coupon VSM values moved in the same direction but muted by bulk dilution -- which is precisely why a bulk measurement of a finished support flatters the finish and a surface-referred one condemns it.

## 4. DEPTH PROFILING: WHERE THE METAL SITS

A susceptibility change tells us the metal is present; it does not tell us where. For a support material the depth distribution is not incidental, because the coupling to the cable falls off steeply with distance and a contaminant buried 2 mm down is electromagnetically far less relevant than the same mass in the first few microns. We profiled the finished coupons by radiofrequency glow-discharge optical emission spectrometry (GD-OES, Horiba GD-Profiler 2), which sputters the surface at roughly 2 to 3 micrometres per second while tracking Co, Mn, Zr, and Fe emission, cross-checked on selected coupons by laser-ablation ICP-MS depth sectioning.

In every oxidative-cure coupon the catalyst metal was confined to the coating and the immediately underlying wood. Cobalt and manganese emission peaked at the surface, held through the 30 to 70 micrometre film thickness, and then fell by more than an order of magnitude across the next 20 to 40 micrometres as the profile entered unpenetrated wood, reaching the substrate 7 ppm background by about 100 micrometres in the worst case (the low-viscosity boiled linseed, which wicks into the surface porosity) and by 60 micrometres for the more viscous varnish. Integrated, better than 90 percent of the deposited paramagnetic metal lay within the top 100 micrometres, and the majority within the top 50. Zirconium tracked cobalt and manganese in depth but, being effectively non-paramagnetic in this coordination, contributed to the profile without contributing to the susceptibility -- a useful internal check that the magnetic signal follows the Co and Mn and not the total metal.

This is the geometrically worst possible distribution for a cable support. The neutrality grade was built on the premise that the wood in contact with the conductor is diamagnetic; the finish inverts that premise by loading paramagnetic metal into the exact 50 to 100 micrometre skin that forms the contact interface, while leaving the deep, electromagnetically irrelevant core of the block as clean as it ever was. A finished support is, magnetically, a thin paramagnetic sheet wrapped around a neutral billet, presented to the cable metal-side-out.

## 5. THE COBALT-FREE DRIER TREND DOES NOT HELP

Cobalt octoate is under regulatory pressure. Cobalt salts of 2-ethylhexanoic acid carry harmonised classification as suspected carcinogens and reproductive toxicants, and the coatings industry has invested heavily in cobalt-free driers over the past decade. The replacements fall into three families: manganese complexes (often with bipyridine or aminomethyl ligands that boost Mn activity to cobalt-like levels), iron complexes (iron with specialised nitrogen-donor ligands, marketed as high-performance drop-in primary driers), and vanadium-based systems. All three are promoted as safer, and for their intended purpose -- replacing a toxic catalyst with a benign one at equal drying speed -- several genuinely succeed.

For our purpose they succeed at nothing. Manganese, iron, and vanadium are all paramagnetic; iron and manganese are the two elements the neutrality grade is specifically defined to exclude. Swapping cobalt octoate for an iron or manganese drier does not remove paramagnetic metal from the surface film -- it substitutes one paramagnetic metal for another, and in the iron case substitutes the single most penalised contaminant on the grade scale. We finished a further set of teak coupons with a commercial iron-bipyridine drier at the manufacturer recommended loading and measured the surface slice at +3.1 x 10^-6, comparable to the cobalt boiled-linseed result and, because the metal is iron rather than cobalt, arguably worse against a grade whose primary axis is iron content. A manganese-neodecanoate drier gave +2.6 x 10^-6.

The lesson is that the cobalt-free trend optimises a toxicological objective that is orthogonal to the magnetic one. There is no oxidative-cure drier chemistry, present or foreseeable, that hardens a drying oil without a redox-active transition metal, and every redox-active transition metal cheap and abundant enough to be a drier is paramagnetic. The finishing industry is not going to solve this problem, because from its point of view there is no problem to solve: a magnetically neutral drier would be a solution in search of a market that consists, at present, entirely of us.

## 6. DISCUSSION: OPTIONS THAT REMAIN

If oxidative-cure finishes are excluded on magnetic grounds, three categories of coating remain formally metal-free: drier-free drying oils, physically-drying and coalescent water-based films, and true evaporative lacquers. Our drier-free tung oil (treatment B) and acrylic dispersion (treatment E) confirmed that these add no paramagnetic metal and hold the grade. They are, however, poor finishes for this specific object. A drier-free oil on a support that must cure fully before it can bear a cable takes weeks to harden and remains permanently soft enough to hold surface metal from the cable clip and from ordinary handling -- it converts the support into a passive collector of exactly the contamination the grade excludes. A water-based acrylic seals the wood but raises its surface permittivity and loss tangent well above bare teak, trading a magnetic problem the grade forbids for a dielectric one the companion study also penalises.

Every finish, in other words, either adds paramagnetic metal (the oxidative-cure oils and varnishes, the whole traditional class), or degrades the dielectric surface (the water-based films), or fails to cure hard enough to resist recontamination in service (the drier-free oils). None of them improves the graded surface, and each of them is a step taken after the wood has already passed every test the grade requires. The finish can only subtract from a grade the raw billet already holds; there is no coating that can add to it, because the quantity being graded is the absence of something, and a coating is by definition an addition.

This reframes the unfinished support from a cost saving or an aesthetic austerity into the only choice consistent with the measurement. The billet is selected, scanned, cored, digested, assayed, and certified to a paramagnetic parts-per-million figure; to then brush a cobalt-catalysed oil onto its working face is to spend that entire process and undo it at the last step, in the most electromagnetically active location, for a film of appearance.

## 7. CONCLUSION

Finishing wood recontaminates it magnetically, and does so at the surface, because the chemistry that hardens a traditional finish is metal-catalysed autoxidation and the catalyst is a paramagnetic transition metal deposited in the film. We measured the effect directly: on a single 5N teak substrate, every oxidative-cure finish -- cobalt boiled linseed, a Co + Mn + Zr spar varnish, and a cobalt hardwax oil -- drove the surface-referred volume susceptibility from a diamagnetic baseline near -6 x 10^-6 to net-positive values as high as +4.8 x 10^-6, reclassifying the graded surface from 5N to below 4N, with better than 90 percent of the deposited paramagnetic metal confined to the top 100 micrometres in direct contact with the cable. Drier-free oils and water-based films add no metal but fail the object on other grounds; the cobalt-free drier trend substitutes iron, manganese, or vanadium and so removes a toxin without removing a single unit of paramagnetic contamination.

The conclusion is narrow and firm. The only finish that preserves a timber neutrality grade is no finish. The unfinished surface oxidises and greys with age, but that patina is elemental oxidation of the wood carbon skeleton and adds no metal; it is a cosmetic change and a magnetic non-event. Equatorial Elevation Blocks therefore ship, and will continue to ship, unfinished -- not because a finish was omitted to save a step, but because applying one would spend the entire grade to buy a shine.

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