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DECAY RESISTANCE AND FIRE CLASSIFICATION OF SURFACE-CARBONIZED SCOTS PINE WITH POST-CARBONIZATION LINSEED OIL AND SODIUM SILICATE TREATMENT

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ABSTRACT

Todetermine the effect on decay resistance and fire classificationof applying linseed oil or a sodium silicate solution to surfacecarbonized Scots pine,two different experiments were conducted. AnAWPA E10 standard (AWPA 20216) soil block test was conducted to determine the decay resistance of eight unique treatment configurations, and fireclassification following the EN 13823:2010+A1:2014 / EN 14915:2013was conducted to determine the fire classification of façade panels treated with pure linseed oil and a 40/60 mix of linseed oil and sodium silicate respectively. The study showed that decay resistancemeasured as average mass loss (AML%) improves significantly by surface carbonization butdepends on the intensity of the treatment as well as the application of surface sealing substances applied post-carbonization. Carbonized Scots pine façade panels without any post-carbonization treatment as well as carbonized Scots pine treated with sodium silicate or a 40/60 mix of linseed oil and sodium silicate solution obtained an EN 13823:2010+A1:2014/ EN 14915:2013 B-s1,d0 fire classification. Carbonized Scots pine treated with pure linseed oil did not obtain any classification under EN 13823:2010+A1:2014/ EN 14915:2013.

KEYWORDS: Scots pine, surface carbonized wood,fungi decay resistance, linseed oil andsodium silicate, fire resistance.

INTRODUCTION

Surface carbonization of wood, often referred to as the Yakisugi/Shou Sugi Ban method, is a traditional Japanese technique that uses intense heat to carbonize the surface of wood,

enhancing the durability and weatherability of façade claddings(Resi 2021; Ebner et al. 2021). Traditionally, the Yakisugi method requiresa post-carbonizationtreatmentwith natural oils or synthetic substances to reduce the bleeding of carbon/char onto the ground during weathering and for aesthetic appeal(Kymäläinen et al. 2022b). Although a limited number of studies have investigated the combined effects of surface carbonization and subsequent oil treatments, the findings remain inconclusive (Žigon & Pavlič 2023). In particular, the impact of natural oils or non-organic substances used in post-carbonization processes on the decay resistance and fire classification of carbonized wood remains largely unexplored.

Surface charring of wood with post-carbonization treatment has the potential to increase the durability and service life of exterior cladding boards by providing protection against wood-destroying fungi, UV-degradation, and weathering, besides improving thestructural stability. Research on Yakisugi indicate that carbonized wood is less susceptible to degradation due to fungi, as the carbonized surface acts as an organic barrier layer shielding the untreated interior from environmental stresses and making the wood less susceptible to degradation due to fungi(Wang et al. 2018; Kymäläinen et al. 2022a; Machová et al. 2021; Buksans et al. 2021; Ebner et al. 2019; Yuan et al. 2022). Likewise, thecarbonized surface improves fire resistance through the process ofpyrolyzing hemicellulose and lignin components thusremoving volatiles(Homan & Jorissen 2004; Martinka et al. 2013; Gosselink et al. 2004).

However, research remains inconclusive about the general efficacy of the Yakisugi method in improving decay resistance. On that matter, research indicates that the efficacy of Yakisugi against rot varies significantly across both the type of fungi used in the tests, the wood species tested, and the application of brushing or sanding the carbonized layer(Kymäläinen et al. 2017; Čermák et al. 2019; Žigon & Pavlič 2023; Peterson et al. 2008). In particular, research on the general durability of carbonized wood surfaces treated with natural oils or synthetic substances post carbonization is still scant, and the results are somewhat inconsistent (Žigon &Pavlič 2023).The enhanced fire resistance of surface-carbonized wood is well established(Machová et al. 2021; Hasburgh et al. 2021; Ebner et al. 2024). However, the influence of post-carbonization treatment with natural oils on fire resistance remains unexplored.

A literature review was conducted following the methodological principles outlined by Hammersley (2001) and Tranfield et al. (2003), encompassing all 34 peer-reviewed articles published between 2008 and 2025 on the efficacy of surface carbonization of wood. Despite Scots pine (Pinus sylvestris) being one of the two most commonly used species for exterior cladding in Northern Europe and Scandinavia, no studies specifically addressed its performance in this context.Furthermore, wood treated with the Yakisugi technique is typically coated with natural oils following the charring process to seal the carbonized surface. In Japan, pure tung oil is traditionally used, although other oils such as hemp oil, linseed oil, and even synthetic coatings like polyurethane are also applied (Šeda et al. 2023). While several studies have investigated the wettability and weathering performance of surface-carbonized wood combined with various coatings, Žigon & Pavlič (2023) highlight that comprehensive knowledge regarding the general

properties and long-term weathering performance of wood protected by charring in combination with coating remains limited.

Accordingly,the objective of this study is to investigate whether post-carbonization treatments with linseed oil or a film-forming sodium silicate solution influence the fire resistance and fungal decay resistance—specifically against *Gloeophyllumtrabeum*—of surface-carbonized Scots pine (*Pinus sylvestris*), and whether these effects are dependent on the degree of carbonization. The choice of sodium silicate was motivated by its surface sealing properties (Giannaros et al. 2016; Zhu et al. 2020), non-toxicity, inflammability, and low price, making it ideal for industrial use, ceteris paribus.

Following the AWPA E10 standard,specimens of Scots pine subjected to different combinations of carbonization intensities and post-carbonization oilor sodium silicate treatments were inoculatedwith *Gloeophyllumtrabeum*mycelium and placed in incubators at 27°C and 70% RH for a period of six months. The efficacy was tested against untreated Scots pine.The fire resistance of carbonized façade panels treated with pure linseed oil and a 40/60 mix of linseed oil andsodium silicate respectively was tested and classified according to the EN 13823:2010+A1:2014 / EN 14915:2013 fire classification.

MATERIAL AND METHODS

The decay test was designed as a fractional experiment with twovariables:“Carbonization intensity”(two different levels)and“Post-carbonization treatment” (four different treatments)using virgin Scots pinefor all.The factorialdesign allowedfor the identification of individual main effects as well assecond-order interaction effects between the two variables.A total of eight unique treatment combinations (2 × 4), each comprising 25 replicates, were tested. Additionally, a control group of 25 untreated specimens was included. Treatment configurations are denoted as [Carbonization Intensity]_[Post-carbonization Treatment], where Carbonization Intensity is either Light or Intense, and Post-carbonization Treatment is one of the following: No treatment (abbreviated ‘No’), linseed oil (abbreviated ‘Linseed’), sodium silicate (abbreviated ‘SS’), or a 40/60% mixture of linseed oil and sodium silicate (abbreviated ‘SSL’). Control samples are labeled No_No. The decision to use 25 replicates per treatment group, resulting in a total of 225 specimens, was based on previous findings indicating low signal-to-noise ratios in studies with fewer than 10 replicates per group.

Sample selection and preparation

To minimize sample bias, all virgin Scots pine samples used in the test were cut from the same three sapwood planks with 3.3-3.5 growth rings per cm. Each sapwood plank was cut into blocks of 20x40x45 mm (20 mm and 40 mm pith side to pith side). A larger block size than the standard used in AWPA E10 tests (10 × 10 × 10 mm) was selected due to the characteristics of the Yakisugi treatment. Using smaller blocks would have resulted in some samples being almost

entirely carbonized, leaving minimal untreated wood at the center.To minimize systematic in-between-sample noise, each of the 9 treatment configurations of 25 samples had the same number of samples from each of the three sapwood planks.Only samples without visible defects and knots were chosen.The average density of the unmodified samples at 63% RH, 21°Cwas 1.1g/cm^3 with a standard deviation of 0.09 g/cm^3.

Surface charring

In our study, direct flame contact using a propane burner—often called modified Yakisugi or open flame charring—was chosen due to its applicability in commercial, large-scale operations; in particular automated/semi-automated high-volume production at low operational costs, the ability to control the uniformity of charring (quality/durability), and the opportunity to offer customers different degrees of charring (product range/aesthetics). The wood samples were treated in one of three ways: "No charring" (control samples), "Light charring" (2 sec. contact exposure to direct propane flame), and "Intense charring" (6 sec. contact exposure to direct propane flame). Light and intense charring respectively represent the polars of Yakisugi treated exterior cladding commercially available Northern Europe.

Each sample group was treated on all six sides. The char depth was microscopely measured from several additional samples. As noted byKymäläinen et al. (2022b), the shift from char to unmodified wood is sharp and easily distinguished, but measuring the depth of the additional thermally modified transition layer between char and unmodified wood is not possible without the aid ofhigh magnification devices such as SEM.The measurement of thermal transition depth was based on color difference visible under 80x magnification using a Zeiss AXIOA1 and should be viewed as conservative estimates.

Post-charring surface sealing treatment

In our study, wood samples were subjected to four different post-carbonization treatments: "No treatment" (control sample), "Linseed oil", "Sodium silicate solution", or "40/60 mix of linseed oil and sodium silicate solution". The linseed oil used was pure linseed oil, and the sodium silicate ($Na_2Si_3O_7$) was a 4% sodium silicate solution by weight in water. Post-carbonization treatment with linseed oiland sodium silicate solution was done by fully submerging each sample in theoil/solutionfor ~2 s.Excessoil was removed with a soft cloth after 10 minutes. After two weeks of drying at ambient humidity, the average saturation per cm^{2}of surface was determined by the average weight increaseas a result of post-carbonization treatment divided by the samples' surface area prior to carbonization.

Decay test, sample inspection, and mass loss calculation

After treatment, following the AWPA E10 standard, each sample wasstored at ambient humidity for 14 days, thenoven-dried at 103 ± 2°C) for 24 h and finally individuallyweighed on a KERN EMS laboratory balanceto determine the initial dry mass ($M_{initial}$) of each sample.All samples were placed on pine wood feederstrips inoculated with

*Gloeophyllumtrabeum*mycelium, a white rot funguscommonly used forsoftwood decay tests,andplaced on sterilized soil in ventilated containers with holes plugged with cotton.The *Gloeophyllumtrabeum*used in the test was acquired from Leibnitz Institute in Germany and was tested for optimal growth at 37°C and a relative humidity (RH) of 70%. The fungus was inoculated onto sterilized feeder strips of Scots pine over a period of 2 months at 37°C and RH of 70%. The samples were placed in a purpose-builtclimate chamberat 37°C and 70% RHfor a period ofsix months. The incubation time of six months was selectedto maximize the signal to noise ratio of each treatment configuration. Once removed from the climate chamber, the samples werecarefully cleaned with a soft brush to remove all adhering mycelium, dried at ambient humidity for 14 days, and then oven-driedat 103 ± 2°C for 24 h and finallyweighted to determine finaldry mass(M_{final}) of each individual sample.Following the AWPA E10 standard, the mass loss of each individual sample is:

$$\text{Mass loss (\%)} = ((M_{initial} - M_{final}) / M_{initial}) * 100 \quad (1)$$

Due to the relatively low number of observations within each sample group (n = 25), it is difficult to assess the distribution of the data. Therefore, we have decided to apply non-parametric bootstrapping to get a more reliable estimate of the variability of the data.

Fire resistance test

Three identical exterior façade panels (Fig. 1) were constructed from Scots pineand charred on the front and sides using contact flame, resulting in a char layer thickness of 2.5-3.5 mm. The back was left untreated.Two panels werespray coated with pure linseed oil anda 40/60 mix of linseed oil and sodium silicate (4% sodium silicate solution by weight in water) respectively. Excessoil was removed with a soft cloth after 10 min. One panel was not coated. The panelswere subjected to controlled fire tests by DBI –The Danish Institute of Fire and Security Technology following the EN 13823:2010 +A1:2014 / EN 14915:2013 and classified accordingly.

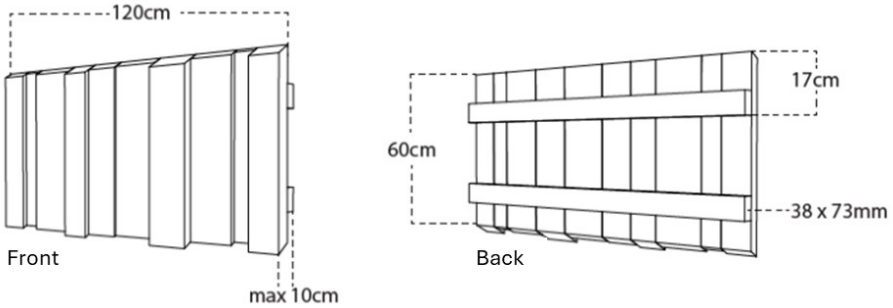

Fig. 1: Fire test of exterior façade panels (Scots pine).

RESULTS AND DISCUSSION

Surface charring can be obtained by three different methods (Ebner et al. 2019,2021,2022; Kymäläinen et al. 2017). Method 1 is the traditional Yakisugi method, where three pieces of wood are tied together with wet rope and charred using burning wood or paper as the heat source. Method 2, often referred to as improved, modified, or enhanced Yakisugi, uses a propane burner transferring heat to the wood by direct flame contact negating the need for tying boards together. Various articles justify this method, as it provides more uniform and reliable results with less variation in quality, making it more suitable for commercial, large-scale operations compared to method 1 (Ebner et al. 2022). Method 3 is contact charring, where heat is transferred to the wood using electrically heated metal plates in direct contact with the wood (Čermák et al. 2019).

As expected, the differences in duration of the direct flame exposure in our study resulted in substantial differences in weight loss, carbonized layer thickness and additional thermal modification depth. A 6 sec. contact exposure ("Intense") resulted in pronounced surface cracking on the pith sides both perpendicular to and in the direction of growth (Tab. 1, Fig. 2a). On average, the intense Yakisugi treatment resulted in ~1.7 cracks per square centimeter of surface with a measured depth on the pith side of 0.8-2.6 mm. In contrast, a 2 sec. contact exposure resulted in no visible surface cracking and a significantly smaller average carbonized layer thickness and weight loss. The formation of substantial surface cracking both perpendicular to and in the direction of growth has beendocumented to correlate with carbonization intensity as well as moisture content(Kymäläinen et al.2017, 2022a, 2022b; Žigon et al. 2023).

Tab. 1: Relative weight loss, carbonized layer thickness, and thermal modification depth from Yakisugi treatment (light versus intense).

Carbonization name	Direct flame exposure time	Weight loss	Carbonized layer thickness	Thermal transition depth
Light	2 sec.	2.3%	0.15 mm	~0.35 mm
Intense	6 sec.	27.1%	2.8 mm	~6.7 mm

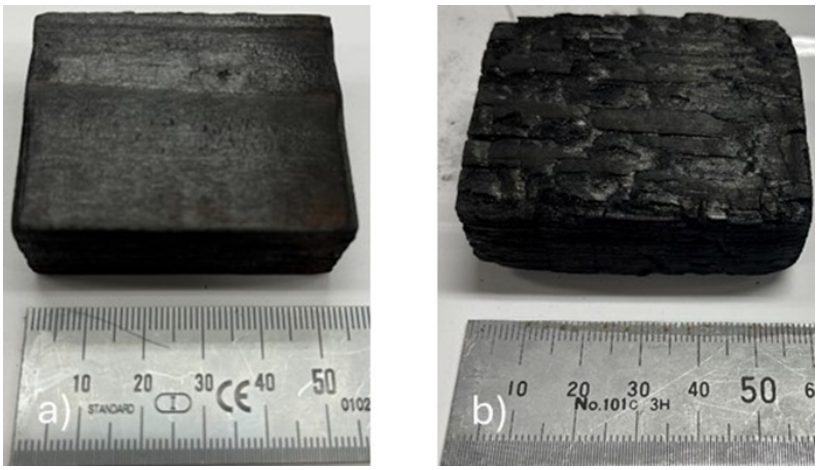

Fig. 2: Visual Yakisugi treatment effects: a = light, b = intense.

The saturation per cm^2 surface area using pure linseed oil was significantly higher for samples subjected to intense carbonizationcompared to Light and untreated wood(Tab. 2), attributable to the porous surface and increased surface area due to surface cracks of highly carbonized samples. The dry-mass saturation for pure sodium silicate was minimal for both untreated and Light specimens, thoughwith a significantly higher saturation for Intense, again attributable to the porous surface and increased surface area. Mixing linseed oil with sodium silicate resulted in a significantly lower saturation compared to pure linseed oil for both Light and Intense. This was expected because of the approx. 56% water content in the linseed oil and sodium silicate solution, combined with the lower viscosity of water compared to linseed oil (i.e., the faster uptake of water is believed to significantly retard the uptake of linseed oil). The increased hydrophobia of the carbonized surface is well documented(Ibanez et al. 2023;Kymäläinen et al. 2018; Kymäläinen et al. 2022b;Soytuerk et al. 2023; Čermák et al. 2019), but studies indicate that wettability depends on wood species and carbonization intensity (Kymäläinen et al. 2017; Tenorio et al. 2024)and theradial or tangential orientation of the wood (Šeda et al. 2021).Water absorption measurements have demonstrated that a thicker carbonized layer exhibited higher water absorption capacity, and thatthe thickness of the charred layer directly correlated with its softness (Ebner et al. 2023).

Tab. 2: Linseed oil and sodium silicate solution uptake (mg/cm^2 surface area).

Treatment name	**Saturation in mg/cm^2**
Light_Linseed	62
Intense_Linseed	269
Light_SS	2
Intense_SS	11
Light_SSL	42
Intense_SSL	73

Mass loss in Scots pine due to fungal decayby *Gloeophyllumtrabeum*

As expected, the highest average mass loss (AML) was found in the unmodified, untreated Scots pine (No_No) where the AML was 54.2% (Fig. 3).Theunmodified, untreated Scots pine samplesshowed visible signs of fungal decay and discoloration andhad changed from hard to spongy/soft.The AWPA E10 standard recommends that minimum weight losses for decay tests on untreated pine sapwood blocks be 40% for the test to be considered suitably aggressive.

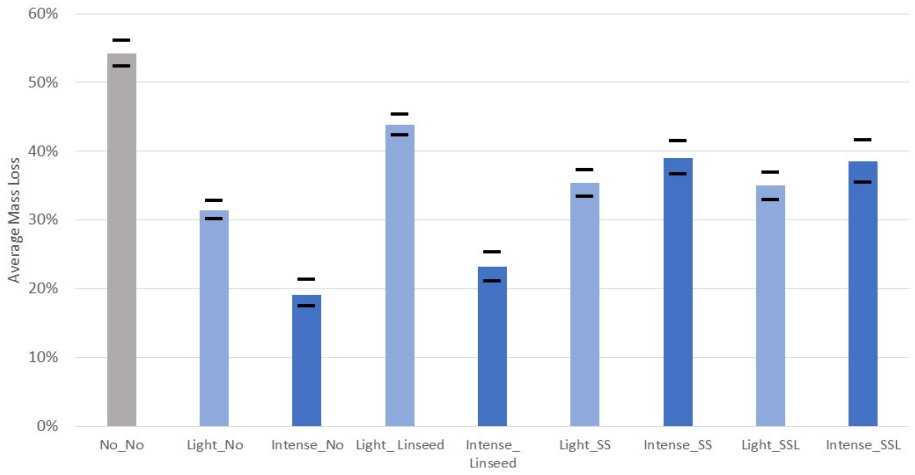

Fig. 3: Average mass loss of Scots pine exposed to Gloeophyllumtrabeum for a period of six months at 37°C and a relative humidity (RH) of 70%.Sample size (n) = 25 for each sample group. Error bars for 95% confidence interval.

The lowest AML was found in samples exposed to intense carbonization with no additional application (Intense_No) where the AML was 19.1%, and samples exposed to intense carbonization with linseed oil application (Intense_Linseed) where the AML was 23.2%. There was no significant difference in AML between the two treatments at a 95% confidence level, i.e. the application of linseed oil had no significant impact on highly carbonized Scots pine's resistance to decay from *Gloeophyllumtrabeum*. For lightly carbonized samples, the application of linseed oil (Light_Linseed) was found to have a significant negative impact on the samples' decay resistance compared to lightly carbonized samples not treated with linseed oil (Light_No). The negative impact from linseed oil on lightly carbonized Scots pine (AML = 43.8%) is not only statistically significant, but also substantial enough tohave practical implications for the durability of exterior cladding.

Post-carbonization application of sodium silicate was found to significantly reduce the AML for lightly carbonized Scots pine (Light_SS) compared to lightly carbonized Scots pine treated with pure linseed oil (Light_Linseed).In contrast,for intensely carbonized Scots pine, sodium silicate was found to have a negative impact on decay resistance compared to applying pure linseed oil (Intense_Linseed) or not using any post-carbonization treatment (Intense_No), all at a 95% confidence level. For highly carbonized Scots pine, the AML of samples with linseed oil application (Intense_Linseed) and without any application (Intense_No)was not different at a 95% confidence level.

The AML for lightly and intensely carbonized Scots pine treated with sodium silicate (Light_SS and Intense_SS) or a mix of sodium silicate and linseed oil (Light_SSL and Intense_SSL) was not different at a 95% confidence level. For intensely carbonized Scots pine, the use of sodium silicate or a mix of sodium silicate and linseed oil resulted in a significantly higher AML compared to intensely carbonized Scots pine treated with pure linseed oil or without

any post-carbonization treatment—i.e. the use of sodium silicate or a mix of sodium silicate and linseed oil is not recommendedfrom a decay resistance perspective.

The resultsindicate that decay resistance, measured as mass loss from fungi exposure, is generally reduced by the application of film-forming substances to surface carbonized Scots pine,but that the effect depends on the specific substance and the intensity of carbonization. The use of film-forming substanceshave shown positiveresults for hydrophobia and expected service life of Norway spruce, European silver fir, Silver birch, and Scots pine (Kymäläinen et al. 2022b; Humar et al. 2025), decreased water sorption in Loblolly pineand*Eucalyptus bosistoana* (Ibanez et al. 2023), whereas other studies found no effect on resistance to weathering of European beech(Šeda et al. 2023), surface roughness, or water uptake in Norway spruce and European larch (Žigon et al. 2023).Our findings suggest, in the context of the above-mentioned studies, that although the application of a film-forming substance post carbonizationreducesthe decay resistance as measured by mass loss in a laboratory setting,further research is needed to include the beneficial effect on other parameters such as increased hydrophobia, contact angle, and wettability.

Macroscopic and microscopic signs of decay by *Gloeophyllumtrabeum*

The surfaces of the unmodified, untreated control samples (No_No) were fully covered by fungi (Fig. 3a). The lightly carbonized samples (Light_No,Light_Linseed, Light_SS, and Light_SSL) showed minimal macroscopic signs of surface fungi growth (Fig. 3b)whereasthe intensely carbonized samples (Intense_No, Intense_Linseed, Intense_SS, and Intense_SS) did not show any macroscopic signs of fungi growth (Fig. 3c), indicating that the carbonized surface provides a poor substrate for decay fungias hypothesized by Kymäläinen et al. (2022a).In line with,i.a.,Soytuerk et al. (2023), da Silva Lins et al. (2023), and Kymäläinen et al. (2022a), our study indicates that although the char layer provides a poor substrate for fungal growth, the layer does not prevent fungal hyphae from reaching the underlying, unprotected wood.

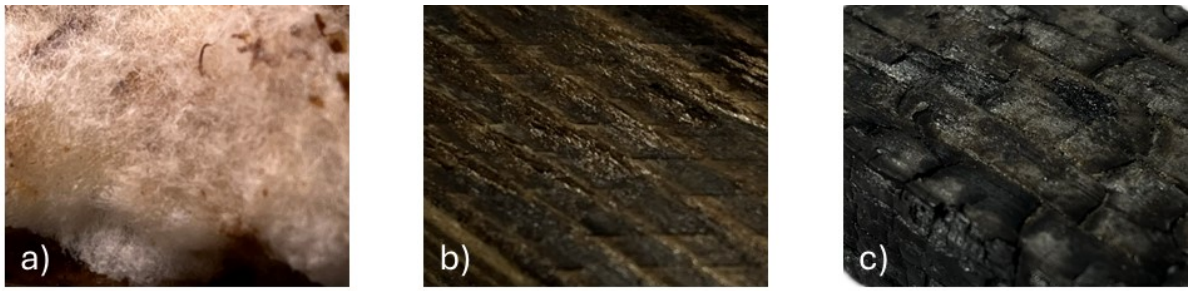

Fig. 3: Surface of unmodified untreated (a), lightly carbonized (b), and highly carbonized (c) Scots pine after 6 months of exposure to Gloeophyllumtrabeum at 37°C, 70% RH.

After weighing, two randomly selected samples from each sample group were split in half and inspected for signs of fungi hypha(Fig. 4).

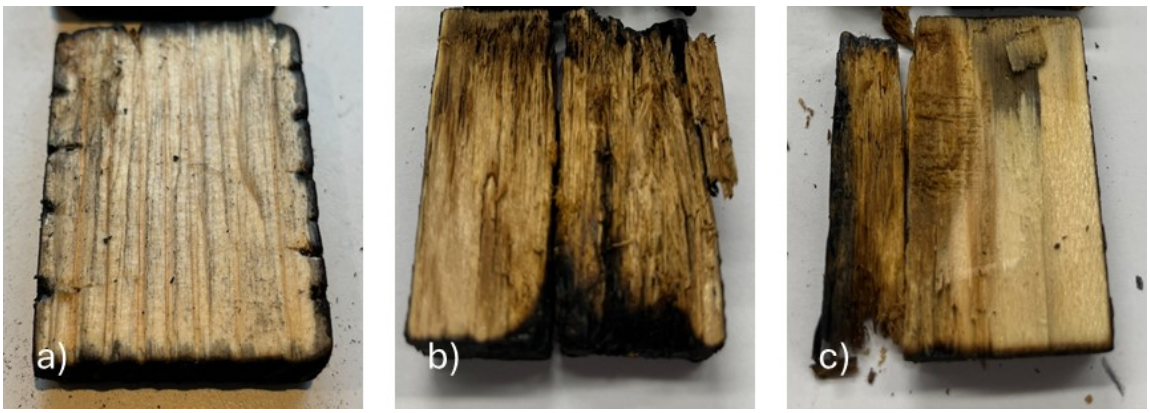

Fig. 4: Fungal growth and decay after 6 months of exposure to Gloeophyllumtrabeum at 37°C, 70% RH. Note: a = Intense_No, b = Light_Linseed, and c = Light_SSL Mix.

Despite minimal fungal growth on the surfaces, all carbonized samples showed varying degrees of decay below the carbonized surface to the center of the untreated wood, and signs of branching, filamentous hypha structure, most pronounced for lightly carbonized samples treated with linseed oil and samples treated with sodium silicate or a mix of sodium silicate and linseed oil.

The Yakisugi process is hypothesized to increase durability by removing surface carbohydrates, producing a hydrophobic surface char layer, and infusing the remaining wood with smoke from the charring process releasing volatiles in the smoke that may have fungistatic properties (Hasburgh et al. 2021; Kymäläinen et al. 2022a). Our study indicates this to be the case for Scots pine although the fungistatic properties of the char layer and the infused smoke seem limited to a small region below the carbonized surface layer, leaving the untreated center of the wood susceptible to fungi infestation. We found that the efficacyof this layer against fungal decay depends on the intensity of the treatment and thus the layer thickness and thermal modification depth, indicating that intense treatment is preferable from a decay resistance perspective. But exposure to temperatures exceeding 400°C may create a brittle char layer prone to cracking or flaking, reducing the layer's protective capabilities (Kymäläinen et al. 2022a) and questioning the longevity of the treatment (Žigon & Pavlič 2023). Conversely, temperatures around 250°C to 300°C can yield a more stable char layer, as indicated by studies on both traditional Yakisugi and modern charring methods such as contact heating (Ebner et al. 2021; Kymäläinen et al. 2022a). Kymäläinen et. al. (2022b) argue that the lower decay resistance noticed with flame charring, despite the surface being further thermally degraded, could be due to the cracked, porous substance providing access for fungal hyphae into the underlying unmodified layers of the surface carbonized wood (Šeda et al. 2023).

Even though the carbonized surface provides a poor substrate for fungal growth, our study, in line with the majority of published findings, also indicates that the layer of modified wood does not provide an impenetrable barrier against fungi. Improved resistance against brown rot (strain *C. putenana*) and white rot (strain *T. Versicolor*) in both Norway spruce (*Picea abies*) and Silver birch (*Betula pendula*) modified by contact charring and flame charring respectively has been found, with a significantly larger effect on contact modified wood (Kymäläinen et al. 2022a). Our study indicates that saturating the carbonized surface layer with an organic oil improves the carbonized surface's properties as a substrate for fungal growth, allowing for faster fungal penetration towards the unmodified wood at the center of the specimens, thus reducing the decay resistance significantly for lightly carbonized Scots pine.Our findings regarding Scots pine contradictŠeda et al. (2023) who found oil impregnation significantly improved the resistance of European beech (Fagus sylvatica L.) charred at temperatures above350°C.For highly carbonized surfaces, we suspect the pure linseed oil did not saturate the entire carbonized surface layer, whereas the much thinner layer of carbonized wood on lightly carbonized samples could be fully saturated with linseed oil. The reduced decay resistance found in samples treated with a mix of linseed oil and sodium silicate regardless of the carbonized layer thickness could be the result of the solutions' significantly lower viscosity, enabling a deeper penetration of the substrate-improving linseed oil. Further research is needed to test this hypothesis.

Fire resistance tests

Surface carbonized wood is traditionally coated with natural oils after charring to seal the carbonized surface, which reduces the "bleeding" of carbon/char onto the ground when the wood is exposed to weathering and to enhance its aesthetic appeal. Alternatively, the carbonized surface layer can be removed by brushing post charring. Wood surface modification improves reaction to fire performance of modified wood, when the char layer remains as facing, but decreased fire performance has been observed, when the char layer is removed by brushing (Buksans et al. 2021). Higher water absorption has been observed in samples treated with charring, while removal of the char layer by brushing contributed to lower water uptake (Žigon & Pavlič, 2023).Several studies have shown that surface carbonization improves wood's fire resistance when the char layer is sufficiently thick (i.e., >1.5 mm.) and remains as facing (Ebner et al. 2024; Hasburgh et al. 2021; Machova et al., 2021), but decreased fire performance has been observed, when the char layer is removed by brushing (Buksans et al. 2021).

In ourstudy, carbonized Scots pine panels without any post-carbonization treatment as well as carbonized Scots pine panels treated with a 40/60 mix of linseed oil and sodium silicate solution both obtained anEN 13823:2010 +A1:2014 / EN 14915:2013 B-s1,d0 classification. The B-s1,d0 classificationallows for the use of façade panels on wallswith a height ofup to 22 meters above ground level. Carbonized Scots pine treated with pure linseed oil did not obtain anyclassificationunder EN 13823:2010 +A1:2014 / EN 14915:2013, as the ignition time of the test panel exceeded that of any of the classification levels, severely limiting the commercial use within the European Union. We conjecture that out findings regarding significantly reduced fire

performance from applying linseed oil to highly carbonized surfaces apply to most—if not all—softwood species.

Surface carbonization improves wood's fire resistance (Ebner et al. 2024; Hasburgh et al. 2021), but the use of combustible oils such as linseed oil post carbonization can reduce the carbonized wood's fire classification significantly (EN 13823:2010+A1:2014/ EN 14915:2013), limiting the use of surface carbonized façade claddingwith linseed oil application to one-storage buildings within the European Union.

Our findings raise an important methodological questionpertaining to the validity of the AWPA E10 standard (AWPA 20216) soil block test as a method for assessing the decay resistance of carbonized wood both with and without surface sealing substances. Most noticeably, that the use of high humidity climate chambers, by design, willoverlook the positive effectsfrom the charred layer's hydrophobic properties, well documented in many studies (Hasburgh et al. 2021; Kymäläinen et al. 2022a). The use of inorganicsurface sealing substances such as sodium silicate might improve the charred layer's hydrophobic properties and wettability, and consequently improve decay resistance, but this improvement will not manifest itself in an AWPA E10 standard (AWPA 20216) soil block test.

CONCLUSIONS

Our study found thatdecay resistance, measured as average mass loss (AML%), depends on the intensity (duration) of the surface carbonizationas well as the application of surface sealing substances applied post-carbonization. The lowest AML was found in samples exposed to intense carbonization with no additional treatment (where the AML was 19.1%), and samples exposed to intense carbonization with post-carbonization linseed oil treatment (where the AML was 23.2%). There was no significant difference in AML between the two treatments at a 95% confidence level. For Scots pine subjected to light carbonization, the additional linseed oil treatment was found to have a significant negative impact on the samples' decay resistance (AML = 43.8%) compared to lightly carbonized samples not treated with linseed oil (AML = 31.5%). The use of pure sodium silicate or a 40/60 mix of linseed oil and sodium silicate solution was found to significantly reduce the decay resistance of both lightly and intensely carbonized Scots pine compared to the use of pure linseed oil or not using any surface sealing substances post carbonization.

Our study also found that applying pure linseed oil to carbonized Scots pine significantly reduces the fire classification of façade panels according to EN 13823:2010+A1:2014 / EN 14915:2013 standards. In contrast, applying a 40/60 mixture of linseed oil and sodium silicate solution did not have a statistically significant impact on fire resistance.

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