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Studies of wooden cladding materials degradation by spectroscopy

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Claddings or façades are the outer part of building envelopes. In this study, wooden claddings are exposed to natural and accelerated weathering. The natural climate exposure was performed at a field test site located in Trondheim, Norway. Accelerated climate exposure was performed in the laboratory in an Atlas SC600 MHG solar simulator. Attenuated total reflectance – Fourier transform infrared (ATR-FTIR) spectroscopy was used to characterise surfaces. The objective was to assess degradation by use of FTIR and thereby see how this may be applied to evaluate the service life of wood. Four types of wooden materials were studied; three untreated and one treated with chromated copper arsenate. Surface concentrated cellulose and lignin are the primary wood components used to determine the quality and durability of wood during ageing. It was found that treatment with preservative chemicals and surface roughness has definitive impacts on cladding surfaces and change to the chemical properties of the materials during ageing. The acceleration factor deduced from the Arrhenius equation shows that an increase in temperature lowers the service life of cellulose at a higher rate than the other wood components.

1. Introduction

Wood is a natural resource which is broadly classified as a forest product. Globally there are 4 billion hectares of forests covering 229 countries, corresponding to 30% of the geographical land area in the world. The forest products sector is employing 12·9 million people globally, and in 2004 there was a US $327 billion trade in the forestry sector contributing to 3·7% of the global value of trade (FAO, 2007). Primary wood products accounted for 21% of the value of the global forest products trade in 2004 (FAO, 2007). These huge amounts of wood products, including building claddings, have a role in the carbon cycle as physical carbon pools, because they substitute for more energy-intensive materials and act as raw materials to generate energy.

Claddings or façades are important parts of a built environment. Commonly, claddings are made from stone, glass, metals, polymers or wood (Herzog *et al.*, 2004). However, naturally elegant, untreated wooden claddings are preferred by many designers, architects, builders and users. When exposed to the outdoor climate wooden claddings are attacked by colour or decay fungi (Eggins and Pugh, 1962) that are influenced by the actual climate of the region both at macro as well as micro scales (Brischke and Rapp, 2008). Major climatic degradation factors are wind, solar radiation and wetting by precipitation (Zisis and Stathopoulos, 2009). Potential effects on fungal activity are competition between wood-destroying and non-destroying fungi, antagonism, wood extractives, wood preservatives, permeability, hydrophobicity, distance and contact with infection sources, adverse moisture conditions and ultraviolet (UV) light. The degradation processes are also influenced by the fact that wood is an anisotropic and non-homogeneous material.

Preservative treatment, impregnation, modification (Fojutowski *et al.*, 2009; Welzbacher *et al.*, 2009) and surface paintings deter the wood biodegradation processes and help to increase the durability and service life of wooden components (Lande *et al.*, 2008). Heavy-duty preservatives that are used to treat wood materials for outdoor exposure have been dominated by chromated copper arsenate (CCA), creosote, coal tar, borates, pentachlorophenol and azole-based preservatives (TRADA, 2005). CCA is not permitted for use in places where there is a risk of repeated skin contact, or contact with finished goods for human or animal consumption as stipulated by European legislation (EC, 1976), the US Environmental Protection Agency (EPA), the American Wood Protection Association (AWPA) and the US Consumer Product Safety Commission (CPSC). The European standard EN 350-2 (CEN, 1994), specifies preservative treatment of all timbers that are classified less than level 3 in the durability class. The usefulness of CCA treatment for timber protection in civil constructions has been widely recognised by the wood industry.

Weathering or ageing takes place when wood is exposed to degradation agents (Feist and Hon, 1984; Sjöström, 1993). Continuous weathering of wooden claddings results in cracking of the surface and dead knots falling off (Virta, 2005). Moreover, cascading water on the cladding surface penetrates at higher rates than spraying water. The types of wooden joints also influence the service life (Highley, 1995).

Wooden cladding materials need careful evaluation, maintenance and replacement throughout the period of their service life (Lisø *et al.*, 2006; Smith *et al.*, 2004). The European Union construction products directive (CPD) acknowledges that risks associated with a product vary greatly, nonetheless some essential requirements including the safety of commodities must be satisfied by the product prior to being put on the consumer market (CEN, 2004). Nevertheless, the environmental awareness coupled with the economic recession has shifted builders' attention from demolition activities to refurbishment and restoration of existing building assets (Slavid, 2010). The reasons for using timber in refurbishment are its easy craftsmanship, sustainability and natural complement to other façade construction materials. The cost–benefit aspect is another driving force for using wood as claddings. Moreover, wooden cladding can be designed for the outside of the existing brick, concrete or stone wall to improve its appearance, resist weathering and protect additional insulation (Hislop, 2007). Thus predicting the service life of wooden cladding material has become a more important task than previously. (Nabuurs and Sikkema, 2001). The service life determination of wooden components is a critical research constraint that needs a thorough investigation of material properties before it is possible to make predictions (Brischke and Rapp, 2008; Gupta *et al.*, 2009, 2010; Haagenrud, 1996; Hovde *et al.*, 2008; ISO 2000, 2008; Jernberg *et al.*, 2004; Kalamees, 2002; Sarja *et al.*, 1999; Sjöstrom and Brandt, 1991; Wang *et al.*, 2008).

Fourier transform infra-red spectroscopy (FTIR) is widely used for wood decay characterisation (Faix, 1988; Hinterstoisser and Salmen, 1999; Kollmann, 1968). Even though advances have been made on decay characterisation by attenuated total reflection (ATR–FTIR) more needs to be done on the quantification of wood decay during the exposure period. Several approaches are available for evaluation of results from accelerated tests (Mohammadian *et al.*, 2010). However, there is a lack of data on the behaviour of wooden claddings during weathering and ageing. Rectifying this is the purpose of the current research paper. A number of general research questions are raised, as follows.

(*a*) What are the differences between natural outdoor exposed and accelerated aged wood?
(*b*) What are the differences in ageing between treated and untreated wood?
(*c*) Does surface roughness affect performance of wooden cladding?
(*d*) What are the possibilities for using FTIR to predict service life of wood?

2. Experimental work

2.1 Materials

Four types of wood: rough-surfaced spruce, plane-surfaced spruce, larch and CCA-treated spruce, were exposed to natural outdoor and accelerated laboratory exposure conditions. Details of the wood species used are given in Table 1. Rough surfaces are rough sawn while plane surfaces are machine planed or polished on all sides. Norway spruce (*Picea abies* L. Karst) is the dominant wood species in northern and central Europe and has a huge impact as a scavenger of aerosol and fog and as an environmental archive (Ulrich *et al.*, 2009). Wood moisture content (EMC) at equilibrium condition was determined according to standard guidelines (ISO, 1975). Wood specimens were dried in an oven (Termacks) at 103 ± 2°C to obtain oven-dry (OD) mass and volume. Three replicates were selected for each type of wood to determine the OD properties.

2.2 Exposure

Exposures of test specimens of 50 cm × 15 cm × 2 cm wooden blocks from the heartwood part were performed in two separate environments: first, in an open field for natural long-term testing and second, in a laboratory for short-term accelerated testing. The natural outdoor exposure was performed in Trondheim, Norway (63° 25′ N, 10° 26′ E) for tangential surfaces of materials mounted vertically facing south for 1322 days. The weather in Trondheim represents an arctic climate with occasional rainfall and a long winter. Trondheim is located nearly 500 km away from the polar circle and has a climate that

Wood no.	Wood types	Details	Specific gravity (oven dry)	EMC: %
1	Rough-surface Norway spruce	*Picea abies* (L.)	0·40 ± 0·01	5·0 ± 1·0
2	Plane-surface Norway spruce	*Picea abies* (L.)	0·38 ± 0·01	5·5 ± 0·3
3	Larch	*Larix decidua* Mill.	0·60 ± 0·03	6·1 ± 0·1
4	Spruce pressure treated with CCA	*Picea abies* (L.) class AB (for use above ground) (EN 351-1, CEN, 2007)	0·48 ± 0·04	5·6 ± 0·1

Table 1. Wood and wood properties used for natural outdoor field and accelerated laboratory exposure

might be categorised as 'D' Köppen class, having cold/snow winter with a Boreal forest type of vegetation (Smith *et al.*, 2002). Accelerated ageing was performed in an Atlas SC600 MHG solar simulator (Vötsch Industrietechnik GmbH, Germany) for 42 days. Each exposure comprised 5 h light exposure (600 W/m^2 solar radiation using a 50% UV filter) at 63 ± 2℃, 50% relative humidity and 1 h of deionised water exposure sprayed at 100% relative humidity from two nozzles, each with a discharge of 0·5 l/min on an effective horizontal exposure area of 0·7 m × 0·76 m. Irradiance was produced from a 2·5 kW metal halide global lamp. The accelerated laboratory exposure was performed on the tangential surfaces of wooden specimens placed horizontally and tilted at a small angle to allow a flow of water. Small pieces (chips) were chiselled off from the exposed surfaces of the specimens to obtain FTIR spectra. The results obtained from the natural outdoor exposure and the accelerated laboratory exposures were compared and evaluated.

2.3 Attenuated total reflection (ATR) infrared spectroscopy

Infrared spectral analyses were performed by a Thermo Electron Nicolet 8700 FTIR spectrometer fitted with a Smart Orbit attenuated total reflectance accessory. The wood chips from the specimens were conditioned at room temperature (22℃) and room humidity in a desiccator before spectral measurements were taken. The EMC is provided in Table 2. The exposed surface of the chips was pressed against the ATR diamond crystal. The infrared radiation from the spectrometer at a fixed incidence angle of 45° reflected through the crystal and penetrated into the aged surface of the wood chips by way of an evanescent wave. The mid-IR region of 4000–400 cm^{-1} was evaluated to characterise the materials. A pressure applicator with a rotating knob was used to confirm adequate contact with the ATR crystal. Averages of 32 scans were recorded for a single spot and analysed by using OMNIC software. Three spectra were recorded for each wood chip to obtain representative spectra. Graphs were plotted using Sigma Plot software version 11.00 (Systat Software, Inc.).

2.4 Microscopy

Microscopic images of wooden surfaces were obtained from Olympus BX51 microscope (4 × magnification) fitted with an Olympus DP 71 camera and Olympus Cell–Soft Image software.

			Accelerated laboratory exposure					Outdoor natural exposure
Wood no.	Wood types	Unaged	360 h	456 h	624 h	792 h	1008 h	
1	Rough-surfaced Norway spruce	70	51	54	57	36	44	67
2	Plane-surfaced Norway spruce	64	55	33	26	39	29	37
3	Larch	58	43	40	46	47	45	48
4	Spruce pressure treated with CCA	70	58	53	48	48	46	37

Table 2. Transmittance (%) for 1024 cm^{-1} IR band assigned to cellulose C–O–H bond

3. Results and discussion

Table 1 demonstrates that larch has comparatively higher density and equilibrium moisture content (MC) (%) than spruce. Rough-surfaced spruce and plane-surfaced spruce have similar specific gravity and MC properties, while the CCA-treated spruce has a somewhat higher specific gravity, owing to chemical deposition. Initial visual inspection confirmed that ageing causes discoloration and degradation at natural outdoor and laboratory conditions. Exposed surfaces lost their shiny appearance after ageing. Surface checks, stains, pith cracks, edge cracks and knot cracks were visible for exposed wooden specimens. Similar observations have been recorded by previous researchers (Evans *et al.*, 2008).

3.1 Interpretation of FTIR spectra

FTIR spectra are good evaluation tools for chemical characterisation. The mid-IR region of 4000–400 cm^{-1} was the region of interest since most of the functional groups show their characteristic IR bands in this region (Figure 1). The absorbance (A′) of a pure specimen is governed by Beer–Lambert's law as $A' = \log_{10}(1/T)$, where T is transmittance. Wood spectra show carbonyl, hydroxyl, ester and ether functional groups along with carbon–hydrogen bonds originating from cellulose, lignin, hemicellulose (xylan, mannan) and extractives that are mostly phenolic in nature. Broad bands at 3600–3000 cm^{-1} represent characteristic water absorbance of the wood materials. A strong hydrogen bond O–H stretching absorbance at ~3400 cm^{-1} and C–H stretch at 3000–2890 cm^{-1} were observed in each collected interferogram. The fingerprint region of 1800–600 cm^{-1} was selected to detect the chemical functionalities present on the surface. Specifically, the following characteristic bands for wood material were investigated: 1738–1734 cm^{-1} for C=O stretching of xylans; 1640–1630 cm^{-1} bending for absorbed O–H from water; 1520–1505 cm^{-1} for aromatic unit in lignin (Rodrigues *et al.*, 1998); 1425 cm^{-1} for asymmetric C–H deformation in lignin and carbohydrates; 1375 cm^{-1} for C–H deformation in cellulose and hemicellulose; 1330–1320 cm^{-1} for C–H vibration in cellulose and C–O vibration in syringyl derivatives; 1268 cm^{-1} for aromatic C–H in plane ring bending vibration of lignin, C–O stretch in lignin and for C–O linkage in guaiacyl aromatic methoxyl groups; 1158 cm^{-1} for C–O–C vibration in cellulose and hemicellulose; 1024 cm^{-1} for C–O stretch in cellulose and hemicellulose; and 898 cm^{-1} for C–H deformation in cellulose (Pandey and Pitman, 2003; Robotti *et al.*, 2007). As an example, the IR transmittance values at 1024 cm^{-1} assigned for the cellulose–OH peak (Langkilde and Svantesson, 1995) for unexposed rough-surfaced spruce, plane-surfaced spruce, larch and CCA-treated spruce are 70%, 64%, 58% and 70% respectively, as given in Table 2.

3.2 Accelerated laboratory exposure

3.2.1 Rough-surfaced spruce

The accelerated climate exposures at controlled conditions degrade wood by chemical and physical processes. Figure 2 shows that rough-surfaced Norway spruce has rising transmittance intensities with increased time of ageing at 1321 cm^{-1}. Minimum peak intensities for the fingerprint region were

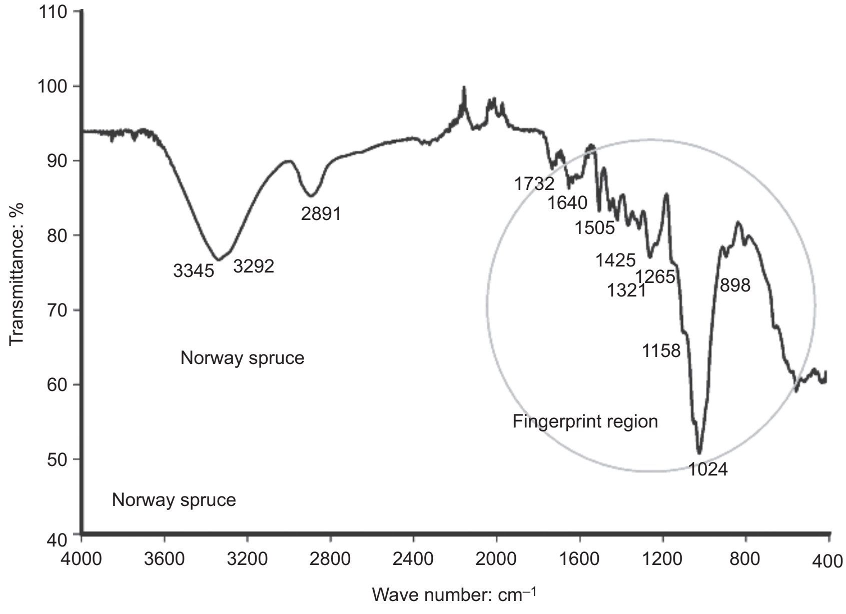

Figure 1. FTIR spectra for wooden surface, rough spruce (wood no. 1)

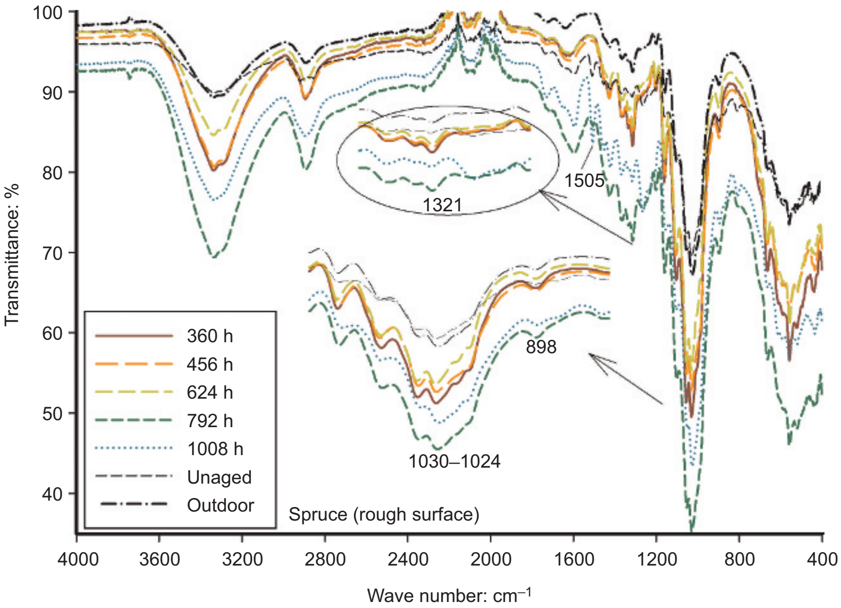

Figure 2. Transmittance spectra for rough-surfaced spruce (wood no. 1)

obtained for specimens aged for 624 h, whereas maximum peak intensities were obtained for specimens aged for 792 h. The movement of extractives from the inner core to the surface during UV exposure could be a possibility for such observation. The change in wood surface chemical composition, surface roughness and wettability during ageing has been discussed by previous researchers (Gardner *et al.*, 1991). The C–H deformation band for cellulose at 898 cm^{-1}, C–O stretching band for cellulose at 1023–1030 cm^{-1}, C–H vibration band for cellulose and C–O vibration band for syringyl derivatives at 1330–1325 cm^{-1} were clearly distinguished for all levels of ageing. The spectra at all levels of ageing displayed nearly the same pattern. Also it was notable that the exposed specimens showed higher intensities for the peaks in the fingerprint region, especially for the cellulose and lignin peaks. Table 2 shows that the IR transmittance at 1024 cm^{-1} is low at higher levels of accelerated exposure.

3.2.2 Plane-surfaced spruce

Plane-surfaced spruce in Figure 3, however, demonstrates that there is a little variability in spectra compared to the rough-surfaced spruce specimens. The C–H deformation band for cellulose at 898 cm^{-1} is visible. Ageing increased spectral intensities and maximum peak heights were observed for specimens aged for 624 h. The peak at 1640 cm^{-1} for absorbed O–H was present for all levels of aged specimens. The peak at 1425 cm^{-1} for C–H deformation in lignin and carbohydrates was also absent in the rough-surfaced spruce spectra. The band at 1321 cm^{-1} both for C–H vibration in cellulose and C–O stretching band for lignin were observed to increase distinctly in intensity with increasing exposure period. Table 2 shows that the IR transmittance at 1024 cm^{-1} loses intensity with increasing periods of exposure.

3.2.3 Larch

The spectra given in Figure 4 for larch illustrates that ageing increased the intensities of spectral peaks especially in the zone of C–O vibration band at 1321 cm^{-1}. The C–H deformation band for cellulose at 898 cm^{-1} is visible. Maximum intensity was observed for specimens aged to 1008 h in this region. All spectral peaks were similar to spruce. The band at 1321 cm^{-1} for C–H vibration in cellulose and C–O stretching band for lignin were observed to increase similarly in intensity with increasing exposure period. Increase in intensities of the O–H broad band at ~3300 cm^{-1} possibly occurred owing to a greater amount of water adhered to aged surfaces. Table 2 shows that IR transmittance at 1024 cm^{-1} for different periods of exposure is random.

3.2.4 CCA-treated spruce

For CCA-treated spruce, the ageing process increased the intensities for chemical moieties as presented in Figure 5. Maximum intensity in the fingerprint region was observed for specimens aged to 1008 h. The C–H deformation band for cellulose at 898 cm^{-1} is visible. New peaks appeared at 660 cm^{-1}, 558 cm^{-1} and 519 cm^{-1}. Previous researchers have demonstrated that the consecutive chemical pathway by which CCA preservative fixation and leaching in wood takes place, depends on the wood species, temperature and time (Radivojevic and Cooper, 2007). It is known that the

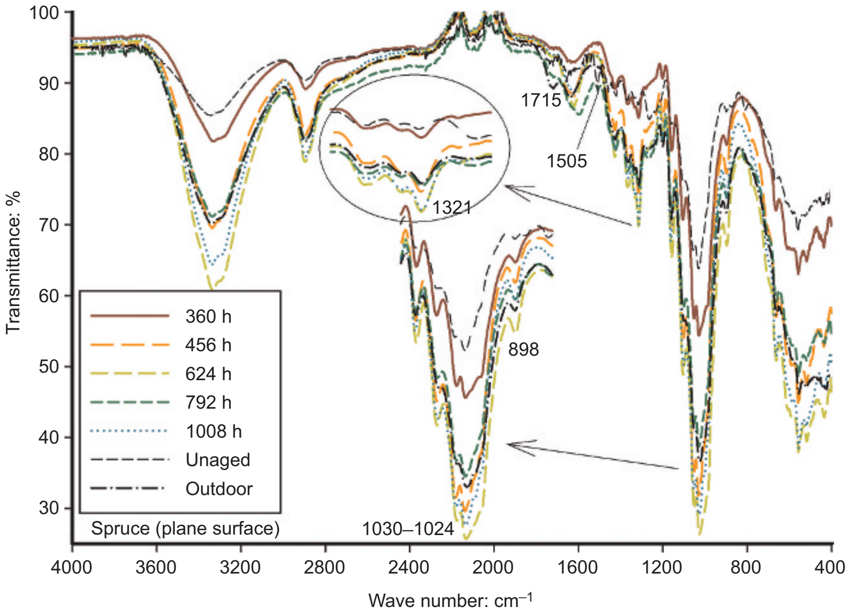

Figure 3. Transmittance spectra for plane-surfaced spruce (wood no. 2)

chromium fixation to the wood matrix occurs late compared to arsenic and copper fixation. So, the variability in spectra in Figure 5 between ageing durations is not surprising. Table 2 shows that the IR transmittance at 1024 cm^{-1} assigned for the cellulose–OH peak has a gradual decrease. Thus, unlike the untreated wood, treated wood had the appearance of new peaks in regions at low wave numbers. CCA-treated spruce has a much more regular decreasing pattern than the other types of

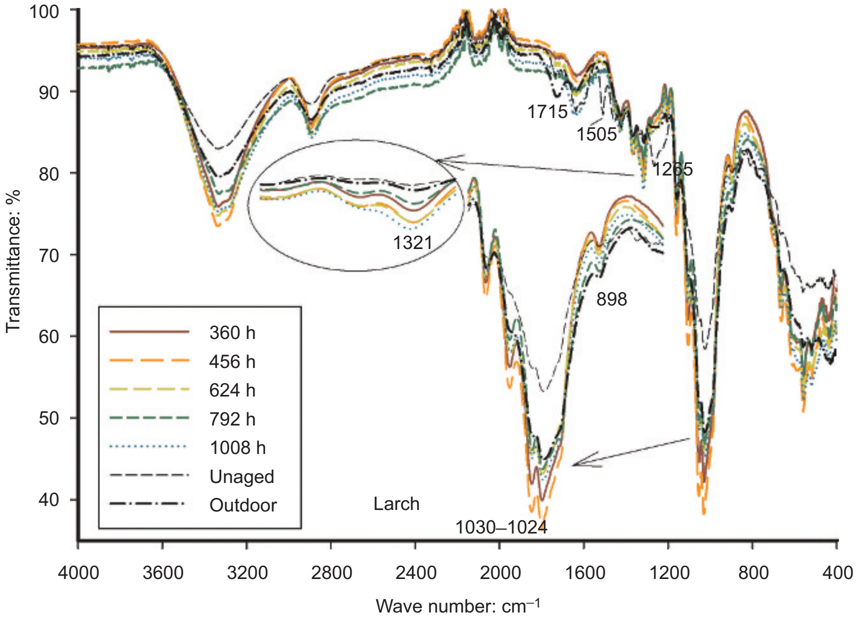

Figure 4. Transmittance spectra for plane-surfaced larch (wood no. 3)

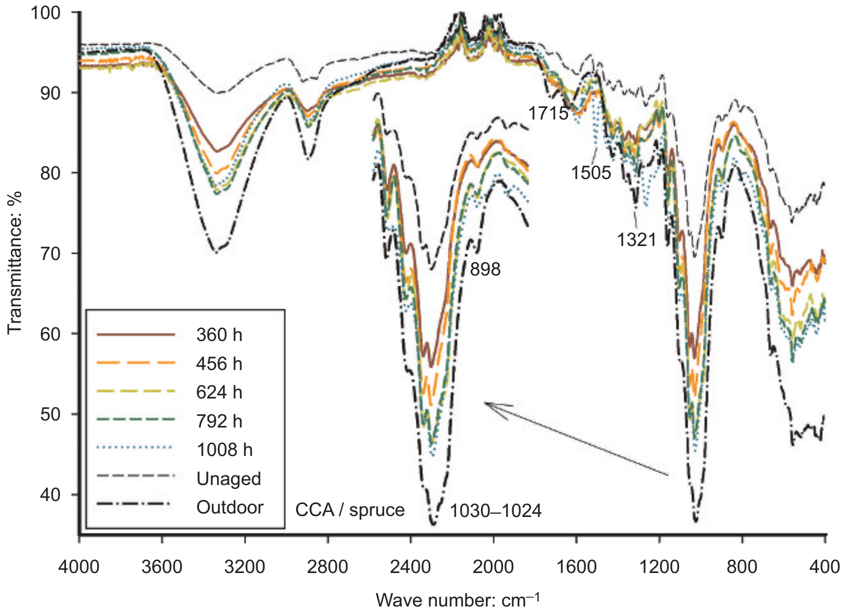

Figure 5. Transmittance spectra for plane-surfaced CCA treated spruce (wood no. 4)

wood. Erosion of degraded wood components from accelerated aged surface due to water flow could be a possible reason for spectral peaks of variable intensities.

3.3 Natural outdoor exposure

The specimens with natural outdoor exposure experienced a broad range of solar radiation, water exposure and attacks by biological agents that are significantly different from the environment in the laboratory solar simulator. In the outdoor tests, the specimens were secured in a vertical frame facing south for physical degradation due to wind, particles, solar radiation, rain and snow. The test site location is an open area and it is unlikely that there was any influence from buildings or the forest on ageing conditions. Additionally, the site has a meteorological station owned by the Norwegian Meteorological Institute providing additional information regarding annual precipitation, temperature and wind. Mechanical degradation has possibly taken place owing to long-term stress by weather. Visible cracks on the surface along with physical deformation like bowing and cupping were observed. Most importantly, outdoor exposure invites biological degradation that is an essential parameter for service life modelling accompanied by the mechanical loads. However, no visible decay or rot attack was found on the mounted wooden specimens.

The FTIR transmittance spectra demonstrate that there is a difference in spectral pattern between the four wood types after outdoor exposure. The spectral peaks for the fingerprint region were quite discernible. Also, there is a difference in plane-surfaced spruce and rough-surfaced spruce surfaces. Plane-surfaced spruce, larch and CCA-treated spruce show greater peak intensity at 1715 cm^{-1} compared to accelerated aged wood. The cellulosic O–H peak intensity in Table 2 is in the following order: CCA-treated spruce, plane-surfaced spruce, larch then rough-surfaced spruce. There is a noticeably large difference in transmittance between the rough and plane surfaces. CCA-treated spruce had least transmittance in the cellulose O–H peak. Rough-surfaced spruce showed higher transmittance of cellulose at the surface compared to plane-surfaced spruce. Consequently, it can be concluded that the variety in degradation mechanisms for the outdoor exposure conditions depends on the nature of the species and surface used. Comparing the values from Section 3.1, outdoor exposure reduces the amount of transmittance from cellulose while increasing the amount of transmittance from lignin moieties.

3.4 Image study

Figures 6(a)–6(d) show the microscopic images of wood surfaces aged at accelerated laboratory exposure conditions. All wood surfaces lost their original colour. Spruce and larch became darker. Rough-surfaced spruce in Figure 6(a) shows roughness even after exposure. Microscopic properties of sawn surfaces have been discussed by other researchers (Donaldson *et al.*, 2007). CCA-treated spruce in Figure 6(d) has a greenish tinge on the surface, possibly attributable to salt deposition.

3.5 Durability and evaluation of service life

The cellulosic C–H deformation peak at 898 cm^{-1} is selected since it is distinctly present in all treated and untreated test specimens. Moreover, owing to the uniqueness of the selected

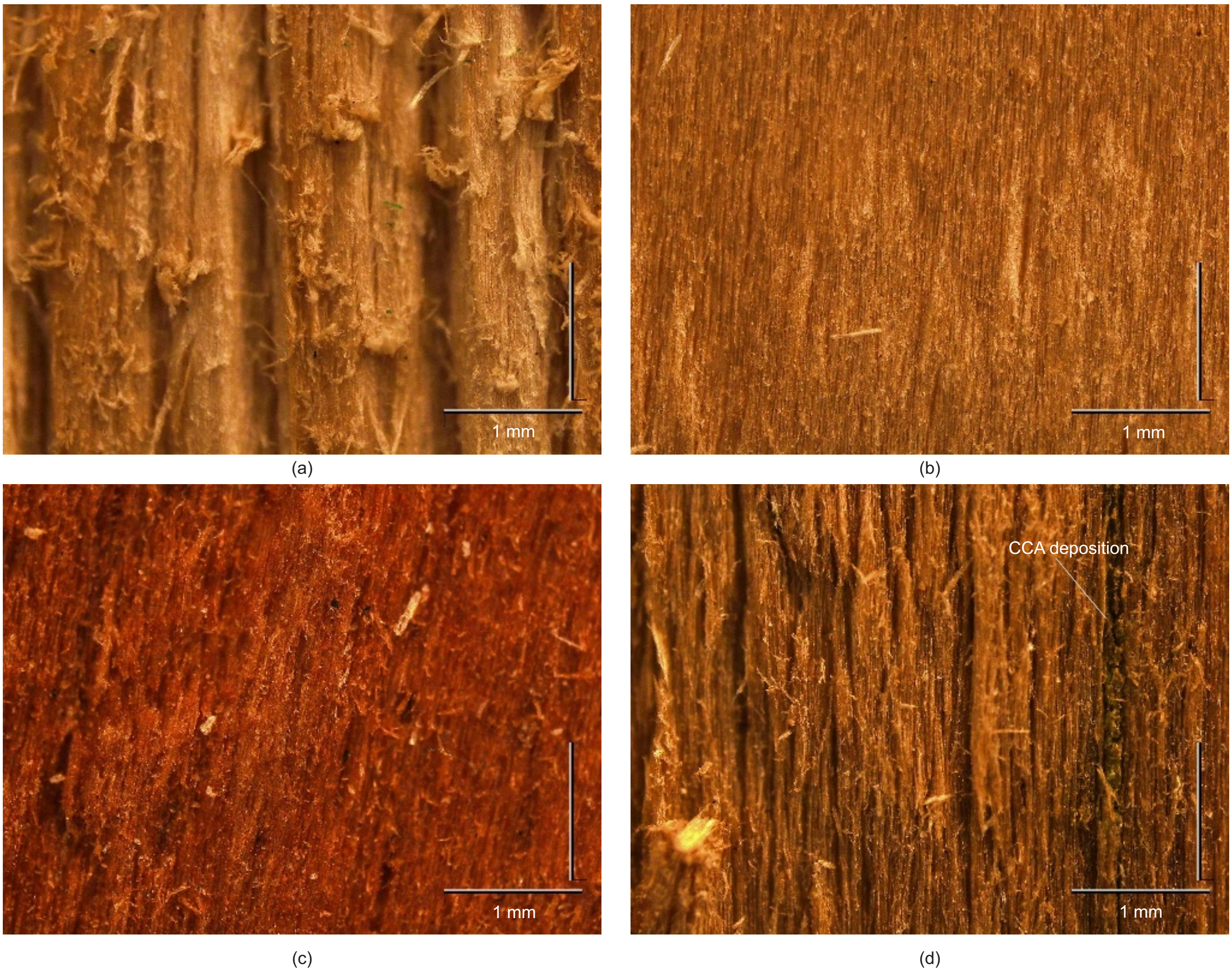

Figure 6. Microscopic images: (a) rough-surfaced spruce; (b) plane-surfaced spruce; (c) larch; (d) CCA-treated spruce

IR region, it has less chance of being masked or influenced by other chemical and physical treatments. Outdoor exposure has a distinguishable effect on untreated and CCA-treated spruce. It is evident that larch has minimum changes in intensities for different periods of ageing, indicating minimum degradation and hence better durability and service life compared to the other test species. Larch has the smallest IR transmittance change, while rough-surfaced spruce has the largest change. Moreover, rough-surfaced spruce was affected differently to plane-surfaced spruce for both outdoor and accelerated ageing exposure. Therefore, surface roughness is an important factor to consider for wooden cladding materials and this study found that the rough surface experienced higher deterioration for both outdoor and laboratory exposures. Comparing the untreated and treated conditions, CCA-treated spruce showed better durability than rough-surfaced spruce. The time-dependent condition (Morris, 2005) of a preservative-treated wood on a scale of 100 (sound) to 0 (broken), is

$$\text{Treated wood condition} = 100 - e^{A}(\text{retention})^{B}(\text{time})^{C} \tag{1}$$

The exponential term e^{A} varies according to the test site and the durability of the material; B describes the diminishing relationship between preservative retention and decay rate, while C describes the increasing rate of decay with time at the loss of preservative chemicals. CCA-treated wood follows the first-order (linear) term (Morris, 2005).

It is known that cellulose micro fibrils are the main component that provides strength in wood. Cellulose degradation is an on-going field of research. In the present study, it was found that larch gives the best performance after exposure with the maximum amount of cellulose and lignin concentration at the surface. Plane-surfaced spruce performed better than the rough-surfaced spruce. However, for the CCA-treated wood there is likelihood that the cellulose and lignin peaks might become masked by the treatment chemical. This is because normally CCA-treated wood has better ageing performance than untreated wood. Nevertheless, there are reports of brown rot having a high tolerance level against CCA (Guillen *et al.*, 2009). However, high tolerance is limited to a few species of fungi while most other biological decay agents have poor tolerance against heavy metals like copper and arsenic. Generally, heartwoods have higher durability than sapwoods.

Previous researchers have found the loss of lignin to be the primary indicator of degradation owing to weathering (Gunnells *et al.*, 1994). Although visible light (λ = 400–750 nm, <70 kcal/mol $\equiv$ 299 kJ/mol) can penetrate about 2540 μm (Hon, 2001) into wood, the energy associated with it is insufficient to cleave a wood component chemical bond. Ultraviolet light (λ > 340–320 nm, <89 kcal/mol $\equiv$ 374 kJ/mol), on the other hand, penetrates less than 75 μm and degrades wood more, especially in the presence of water (Hon, 2001). The UV damage (Martin *et al.*, 1994) is performed by absorbed photons. The time-dependent total effective UV dosage D_{Tot} at any time t is given by

$$2. \quad D_{\text{Tot}}(t) = \int_0^t \int_{\lambda_{\min}}^{\lambda_{\max}} E_0(\lambda,t) \times \left[1 - \mathrm{e}^{-A(\lambda)}\right] \phi(\lambda)\, \mathrm{d}\lambda\, \mathrm{d}t$$

where E_0 (λ, t) is the UV spectral irradiance in W/m^2 per nm, [$1 - \mathrm{e}^{-A(\lambda)}$] is the spectral absorbance of the material and $\phi(\lambda)$ is a quasi-quantum efficiency of the absorbed radiation. Photons at shorter UV wavelength λ_i carry higher energy and can be more damaging than the photons at higher UV wavelength λ_j. So, it was expected that the wood materials exposed in the Atlas solar simulator would undergo higher degradation than the wood exposed to natural conditions. The overall acceleration factor in terms of degradation occurring in the Atlas solar simulator compared to natural outdoor exposure is still to be determined. The observed irregularities in spectral peak heights at different periods of exposure in this study point out that, apart from lignin and cellulose degradation, there were other physicochemical processes that were dictating the time-varied dynamics of degradation. The breakdown of lignin during ageing signifies a loss of service life by the component if the material had been in real service.

Selected high-temperature exposure condition in the Atlas solar simulator was 63°C. Table 3 presents the temperature acceleration factors for degradation of cellulose, lignin, xylan and glucomannan. The acceleration factors have been determined based on the Arrhenius equation (LeVan, 1989). Clearly, a temperature change of 40°C lessens the durability of cellulose by more than a factor of 190 and lignin by more than a factor of 9–70. A similar temperature increase lessens the durability of softwood xylan by a factor of 2 and softwood glucomannan by a factor of 5. The acceleration factor illustrates the rapidity of the degradation process in the solar simulator for accelerated tests as compared to natural exposure (Haillant, 2010). The lower the activation energy (E_a), the lower the rate of loss in service life. Durability can be projected from the data for the inverse of the acceleration factor for the same temperature situation. Since cellulose is embedded in the matrix of lignin and pectin, the overall performance of wood will be dependent on the type and amount of substances present on the wood surfaces.

The superior performance of larch wood is anticipated since it is a well-known species having high resistance against degradation factors; also, larch possesses higher specific gravity than the other wood materials studied in this work. Overall, it can be said that wood quality deteriorates during both natural and accelerated weathering.

No.	Component	E_a: kJ mol^{-1}*	Room temperature: °C	Final temperature: °C	Acceleration factor
1	Cellulose	109–151	23	63	194–1476
2	Lignin	46–88			9–70
3	Softwood xylan	13			2
4	Softwood glucomannan	34			5

*(LeVan, 1989)

Table 3. Temperature acceleration factors for wood components

Over the last few decades, methods and procedures for the determination of the service life of building materials and components have been developed and standardised. Predicted service life is defined as a service life predicted from recorded performance over time of the materials or components, and an extensive investigative procedure has been described in an international standard (ISO 15686-2, ISO, 2001). Estimated service life is defined as the service life that a building or parts of a building would be expected to have in a set of specific in-use conditions, calculated by adjusting the reference in-use conditions in terms of materials, design, environment, use and maintenance. The procedure is described in another part of the same standard (ISO 15686-8, 2008). To determine the estimated service life (t_{ESL}), the material quality (Kalamees, 2002) obtained from testing or inspection (ϕ_A) is used along with the reference service life (t_{RSL}) and a number of other factors, as given by

$$t_{\mathrm{ESL}} = t_{\mathrm{RSL}} \times \phi_A \times \phi_B \times \phi_C \times \phi_D \times \phi_E \times \phi_F \times \phi_G \tag{3}$$

where A is the inherent performance level, B is design level, C is work execution level, D is indoor environment, E is outdoor environment, F is usage conditions and G is maintenance level. According to Eurocode 5 and EN 1995-1, external wall claddings not in ground contact can be categorized at service class 2 and hazard class 3 having risks of attacks by fungi (Gobakken, 2010), stain and insects (EN 335-1, CEN, 2006; EN 335-3, CEN, 1996). Henceforth, it might be concluded that the comparative grading of wood quality by FTIR can be used as input to factor ϕ_A in Equation 3 to estimate service life of a wood component in practice. This application of FTIR data should be developed further to evaluate the possibilities to determine a value for factor A of the so-called 'Factor method' as given in Equation 3. However, the ISO committee TC 61/SC 6 is working on preparing an international standard regarding the methodologies to perform analysis and interpretation of photo-ageing processes evaluated by FTIR and UV spectroscopy (ISO/FDIS 10640, 2010).

4. Conclusion

Ageing of four types of wooden specimens was performed under natural outdoor field conditions and accelerated laboratory conditions. For outdoor exposure, the degradation agents are solar radiation, heat, rain, snow and biological agents. For the accelerated conditions, UV radiation, heat and water were the prime factors for the degradation of wood components. ATR–FTIR was used to evaluate the ageing of wood. Ageing for different time intervals produced IR spectra of different intensity. The IR bands originated from O–H, C–O–C and C–O vibrations were the main regions of interest. The IR band originated at 898 cm^{-1} showed that IR band intensities differed between the wood types. The roughness of the surface creates an impact on wood weathering by increasing the range in transmittance spectra at 898 cm^{-1} during both natural outdoor and accelerated exposure. Natural outdoor exposed wood shows intense peak at 1715 cm^{-1}, which is absent in rough-surfaced spruce. Chemically treated wood produced new IR bands that were absent in the untreated wood.

Acceleration factors calculated from the Arrhenius equation showed that the rate of degradation for xylan and mannan was less than for cellulose and lignin at accelerated conditions with increasing temperature. Durability evaluation was performed by comparing the results obtained from outdoor and laboratory exposure on the basis of surface concentration of cellulose and lignin. Larch was found to have better durability compared to the other specimens tested. A rough surface of spruce performed inadequately compared to a planed surface of the same species. Chemical treatment/preservation method is a good option to increase durability since preservation adds another factor of evaluation. Further studies will be performed to see how the variations in durability can be applied for the determination of the service life of the wood species.

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