Predicting service life of cladding materials is a challenging task. Wooden claddings are the outermost part of the building envelopes and are commonly surface treated or impregnated to increase their durability and service life. There are a number of factors that affect the durability of the wooden claddings. Wind driven rain, solar radiation, temperature, insects and decay fungi are prominent threats. Natural outdoor exposure is needed along with simulated laboratory exposure to compare the findings. In this study, wooden claddings have been aged in outdoor exposure at a field test site in Trondheim and artificially weathered in an Atlas Solar Simulator. The objective is to evaluate the efficacy of the FTIR spectroscopy in predicting service life. Attenuated total reflectance - Fourier transform infrared (ATR-FTIR) spectroscopy has been used as a surface characterizing tool to quantify the wood degradation. Altogether, four types of wood materials were studied, i.e. three untreated and one treated wood type. Preliminary results show that spectral peaks originating from surface concentrated cellulose and lignin might be considered as the two main wood components to determine the quality of wood during ageing. Treatments with preservative chemicals affect surface properties before, during and after ageing. The impact of roughness on cladding surface, during artificial and outdoor exposures, has also been studied. Future research involves quantitative spectral analysis in order to evaluate the scope of FTIR among other parameters to predict durability and service life.

**Keywords:** durability, ageing, ATR-FTIR, service life, wood
1. Introduction

Wood is a natural material and a forest product. Globally there are 4 billion hectares of forests covering 229 countries corresponding to 30% of geographical land area. The forest based industry is employing 12.9 million peoples. In 2004, there was US $ 327 billion trade in forest products sector contributing to 3.7% of the global trade value. Primary wood products accounted to 21% of the value of the forest products trade (FAO 2007). Specifically, Norway has long traditions in the international trade and Norwegian timber products are distributed all over the world. The Norwegian sawmilling industry consists of about 200 mills, spreading all over Norway. The main export markets are Germany, United Kingdom, Netherlands, Sweden, Denmark, Belgium and Japan. These huge amounts of wood products including building claddings have roles in the carbon cycle as physical carbon pool, substitute for more energy-intensive materials and raw materials to generate energy.

Wooden cladding, when brought to outdoor climate exposure, might get attacked by decay fungi. Such decay is influenced by the macroclimate, mesoclimate and microclimate of the region (Brischke and Rapp 2008). Soil type also affects wood degradation (Gramss 1980). External cladding, however, is not supposed to be in contact with ground but is exposed to wetting by rain and snow. Specifically, wood moisture content, temperature and moisture dynamics are the key factors for the fungal growth (Brischke, Bayerbach and Rapp 2006). Vibrational spectroscopy is an excellent tool for surface characterization. A study (Pandey and Pitman 2003) on degradation of wood evaluated by vibrational Fourier transform infrared spectroscopy (FTIR) by three different major wood decaying fungi shows the mean percentage mass losses were 39.8% - 64.3%, after 12 weeks of exposure. This indicates that the amount of mass loss depends on the fungal type (Geib, Jimenez-Gasco, Carlson, Tien and Hoover 2009; Garcia, Latge, Prevost and Leisola 1987). Even though advancement has been made on wood surface characterization by attenuated total reflection (ATR-FTIR), little has been done on the quantification to characterize wood decay (Kos, Lohninger and Kriska 2002; Jelle, Ruther, Hovde and Nilsen 2008).

Mould fungi are much more rapid invaders to wood as compared to the decay fungi. Potential inhibitory effects on fungal activity are competition between wood destroying and non destroying fungi, antagonism, inhibitory extractives, wood preservatives, insufficient permeability, hydrophobicity, distance to infection sources, contact to infection sources, adverse moisture conditions and UV light. The complex fungal degradation of wood is influenced by various parameters including material-inherent properties of wood, abiotic and biotic environmental influences. Service life of wood is a critical parameter and depends on numerous factors (Williams, Jourdin, Daisey and Springdate 2000). Prediction of time lag makes the service life prediction more accurate. The types of wooden joints influence the service life too. For example, the cross brace made of Pine wood has an average service life of 10 years while plank has an average service life of 5 years (Highley 1995). When wood is exposed to harsh environment weathering takes place. Continuous weathering of wooden claddings results to cracking of surface and falling-off of dead knots (Virta 2005). Moreover, cascading water rates on the cladding surface results in higher rates of water entry than compared to spraying water on the cladding surface.
Surface coatings improve weathering performance and increase the service life of wood. Modification of wood has also improved service life (Gobakken and Westin 2008). Chromated copper arsenate (CCA) is a known treatment chemical that has long been used to increase the service life of wooden components. Nevertheless, use of CCA has been under tremendous pressure due to its toxicity to human skin and environment. Results from laboratory testing has confirmed that furfurylated wood obtain decay resistance much greater than samples treated with CCA (Lande, Westin and Schneider 2008). The conclusion is that the resistance to brown and white rot decay fungi is high for furfurylated wood and also has potential for high resistance even in ground contact. However, untreated wooden claddings with natural grain-texture, even having less operating life due to lack of maintenance, may increase aesthetic beauty and decoration of the building that are preferred by many consumers and suppliers.

The above discussion leads to the fact that the prediction of service life for external timber cladding as a building envelope in Norway needs careful examination in line of evaluation, maintenance and consumer satisfaction (Lisø, Hygen, Kvande and Thue 2006). There is lack of data and hence the purpose of this research paper is justified. The research questions and objectives are:

1. What are the differences in effects between outdoor and accelerated ageing on wood species?
2. What are the differences in ageing of treated and untreated wood?
3. Does surface roughness affect performance of wooden cladding?
4. May ATR-FTIR be used to predict service life of wood?

2. Experimental

2.1 Materials

Four types of wood, namely, rough surfaced Spruce, plane surfaced Spruce, Larch and CCA treated Spruce were exposed to natural outdoor and accelerated weathering conditions. Details of used wood species are given in Table 1.
Table 1: Types of wood used for natural outdoor field and accelerated laboratory exposures

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Wood types</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rough surface Norway spruce</td>
<td>Picea abies (L.)</td>
</tr>
<tr>
<td>2</td>
<td>Plane surface Norway spruce</td>
<td>Picea abies (L.)</td>
</tr>
<tr>
<td>3</td>
<td>Larch</td>
<td>Larix decidua Mill.</td>
</tr>
<tr>
<td>4</td>
<td>Spruce pressure treated with CCA</td>
<td>Picea abies (L.) class AB (according to Norwegian classification system for use above ground)</td>
</tr>
</tbody>
</table>

2.2 Exposure

Exposures of test materials were carried out both in field for natural long term testing and in laboratory for short term accelerated testing. The natural outdoor exposure was performed in Trondheim (63º 25' N, 10º 26' E) at a test site with specimens vertically facing south for 1322 days. The weather in Trondheim represents the harsh arctic climate with occasional rainfall and long winter. Accelerated ageing was performed in an ATLAS SC600 MHG Solar Simulator for 42 days. Each ageing cycle consisted of 5 h light (1200 W/m² with 50 % UV filter) at 63 ºC, 50 % relative humidity and 1 hr water 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 x 0.76 m². Irradiance was produced from a 2.5 kW metal halide global lamp. Small chips were scrapped off from the specimen surface. The top exposed surface of the chip was used to collect FTIR spectra. The results from both exposures were compared and evaluated.

2.3 Attenuated total reflection (ATR) spectroscopy

The spectral measurements were performed with a Thermo Electron Nicolet 8700 FTIR spectrometer with the Smart Orbit attenuated total reflectance accessory. The specimens were conditioned at room temperature and room humidity before spectral measurements. Wooden specimens were pressed against an ATR diamond crystal. The infrared radiation from the spectrometer at a fixed incidence angle of 45º reflected through the crystal and penetrated into the sample via evanescent wave. The mid-IR region of 4000-400 cm⁻¹ was evaluated to characterize the specimens. 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 analyzed with the OMNIC software. Moreover, three spectra were collected for each specimen to obtain representative spectra. Graphs were plotted using Sigma Plot software version 11.00 (Systat Software, Inc.).

3. Results and discussions

Initial visual inspection confirmed that ageing cause discoloration and degradation for both the natural outdoor and indoor conditions.
3.1 Interpretation of FTIR spectra

FTIR spectra are good evaluation tools for chemical characterization. The mid-IR region of 4000-400 cm\(^{-1}\) was the region of interest since most of the functional groups show their characteristic absorption peaks in this region (Figure 1).

![Figure 1: Typical FTIR spectra for wooden surface, rough Spruce (sample no. 1)](image)

The absorbance (A´) of a pure specimen is governed by Beer-Lambert’s law as  
\[ A' = \log_{10} \left( \frac{T}{10} \right) \]
where T is transmittance. Wood as a natural polymeric material incorporates carbonyl, hydroxyl, ester, ethyl linkages along with carbon hydrogen bonds. A broad band at 3000-3600 cm\(^{-1}\) represent characteristic water absorption by wood. A strong hydrogen bond O–H stretching absorption at ~ 3400 cm\(^{-1}\) and C-H stretch at 3000-2890 cm\(^{-1}\) was 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, 1738-1734 cm\(^{-1}\) for hemicellulose C=O, 1630-1640 cm\(^{-1}\) for absorbed O-H, 1505-1520 cm\(^{-1}\) for aromatic unit in lignin, 1425 cm\(^{-1}\) for 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 guaiacyl 4-hydroxy-3-methoxy-phenyl unit breathing, 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, were looked for (Pandey and Pitman 2003).

1.2 Artificial exposure

The artificial exposures with controlled conditions can degrade the wood by chemical and physical degradation. Rough surfaced Norway Spruce show increase in absorption intensities with increased time of ageing in Figure 2. Minimum peak intensities for the fingerprint region were obtained for specimens aged for 456 h. Maximum peak intensities were obtained for specimens aged for 792 h. The C–H deformation band for cellulose / hemicellulose, C-O stretching band for cellulose and C–H vibration in cellulose and C–O vibration in syringyl derivatives were clearly distinguished for all levels of ageing. The spectras at all levels of ageing displayed nearly the same pattern. Also, notably the exposed specimens show higher intensities for the peaks in the fingerprint region especially the cellulose and lignin peaks.

Figure 2: Transmittance spectra showing rough Spruce (sample no. 1)
Plane Spruce in Figure 3, however, shows a little variability in absorption spectra as compared to the rough Spruce specimens. Ageing increased absorption intensities and maximum absorption was 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, that was absent in the rough spruce spectra. Possibly the difference in surface texture created contact differences between the ATR crystal and the specimens which, consequently changed the chemical information. Additionally, the peak at 1425 cm$^{-1}$ for C-H deformation in lignin and carbohydrates was also observed that were absent in the rough Spruce spectra. The C-H deformation band at 1321 cm$^{-1}$ for cellulose and C-O stretching band for lignin were observed to increase distinctly in intensity with increasing exposure period.

![Figure 3: Transmittance spectra showing planed Spruce (sample no. 2)](image-url)
Figure 4 for Larch shows that ageing increased the intensity of absorption spectra especially in the zone of C-O absorption. Maximum intensity was observed for specimens aged till 1008 h in this region. All absorption peaks were similar to Spruce. The C-H deformation band at 1321 cm\(^{-1}\) for cellulose and C-O stretching band for lignin were observed to increase similarly in intensity with increasing exposure period.

Figure 4: Transmittance spectra showing planed Larch (sample no. 3)
For CCA / Spruce ageing also increased absorption intensities as depicted in Figure 5. Maximum intensity in the fingerprint region was observed for specimens aged till 1008 h. New peaks appeared at 660 cm\(^{-1}\), 558 cm\(^{-1}\) and 519 cm\(^{-1}\). In overall, unlike the untreated wood, treated wood showed appearance of new peaks in regions at low wave numbers.

![Transmittance spectra showing planed, CCA treated wood (sample no. 4)](image)

Figure 5: Transmittance spectra showing planed, CCA treated wood (sample no. 4)

### 3.3 Natural outdoor exposure

The natural outdoor exposed specimens experienced a broad range of solar radiation and biological agent attacks that are significantly different from the environment in the ATLAS Solar Simulator. For the outdoor tests, the specimens were secured in a frame facing south for physical degradation due to wind, solar radiation, snow and rain. Mechanical degradation has possibly taken place from long term stresses induced by weather inducing small cracks on the surface and deformation. Most importantly, outdoor exposure invites biological degradation that is an essential parameter for service life modeling along with the mechanical loads. The transmittance spectra demonstrate that there is a difference in spectral pattern.
between the 6 wood types. The spectral peaks for the fingerprint regions were quite discernible. Also, there is a difference in plane Spruce and rough Spruce surfaces. The cellulosic O-H peak intensity of 1024 cm\(^{-1}\) are in the following orders: CCA / Spruce (36 %), Larch (48 %), plane Spruce (57 %) and rough Spruce (67 %). Noticeably there is a difference of tenth of an order of magnitude of transmittance between the rough surface and plane surface. CCA treated Spruce showed highest intensity in cellulose O-H peak. Rough spruce surface showed lesser amount of cellulose on surface as compared to planed spruce surface. Henceforth, it can be said that the variety in degradation mechanism at the outdoor condition depends on the nature of the species and surface used.

3.4 Durability and service life prediction

The cellulosic C-H deformation peak at 898 cm\(^{-1}\) is selected since it is distinctly present in all the treated and untreated test specimens. Moreover, it has less chance of getting masked or influenced by other chemical and physical treatments. Outdoor exposure has distinguished effect on untreated and CCA treated Spruce. It is evident that Larch has minimum change in intensities for different periods of ageing indicating minimum degradation and hence better operating life as compared to the other test species. Larch has the smallest FTIR absorbance change, while rough spruce has the second largest change. Moreover, Spruce with rough surface was affected differently than Spruce with plane surface for both outdoor and accelerated ageing exposure. Therefore, surface roughness is an important factor to consider for wooden cladding material and here the rough surface has experienced higher deterioration for outdoor and laboratory exposures. Considering the treated specimens, CCA treated Spruce showed better durability. Larch gives the best performance after exposure with maximum amount of cellulose and lignin concentration on surface. It is known that cellulose microfibrils are the main strength producing component in wood. Cellulose degradation is an ongoing research interest. Surface planed Spruce performs better than the rough Spruce. However, for the treated wood there is a likelihood that the cellulose and lignin peaks might get masked by the treatment chemical. So, probably the treated wood is much better in ageing performance. Nevertheless, there are reports of brown rot having high tolerance level against CCA (Guillen, Navias and Machuca 2009).

4. Conclusion

ATR-FTIR is a quick evaluation tool for determining ageing in wooden specimens. Ageing for different time intervals at accelerated ageing conditions yields spectra of different intensities and new peaks. The C-H, C-O-C and C-O vibration bands were the regions of interest. Vibration bands differed from specimen to specimen. Chemically treated wood produced new absorption peaks that were absent in the untreated wood.

Service life evaluation was done by comparing the results obtained from outdoor and laboratory exposure on the basis of surface concentration of cellulose and lignin. Larch was predicted to have longer service life compared to the others. A rough surface performed poorly as compared to a planed surface. For
outdoor exposure, the deterioration of wooden cladding materials resulted primarily due to UV-radiation, rain, snow and biological agents. Intense sunlight, both the ultraviolet and visible spectrum photo-oxidizes wood. This results in discoloration. Chemical treatment/preservation method is a good option to increase service life. CCA treatment is banned in many countries due to its toxic nature. Furfurylation of low cost Pine wood might be an option to enhance the service life of cladding/ façade components as an alternative to chromated copper arsenate treatment. Future research could be on the evaluation of peaks appearing below 600 cm\(^{-1}\) for understanding the mechanism of degradation in treated wood. Also, optimization of laboratory ageing condition to obtain controlled degradation could be another area of research interest. However, the applicability on the extent of using FTIR signals to predict service life will still be a research question.

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References


