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Section 4 **Processes and properties**

Corrosion of fasteners in heat-treated wood – progress report after two years' exposure outdoors.

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Abstract
The corrosion of common fastener materials now in use - mild steel, zinc-coated steel, aluminium and Sanbond Z-coated steel – has been evaluated after two years' exposure outdoors in untreated and heat-treated spruce (*Picea abies*) respectively.

Spruce from South-western Sweden was used. The heat-treatment was carried out in Finland according to the ThermoWood process at a maximum temperature of 220 °C for five hours.

The results so far show that the corrosion of fasteners in heat-treated wood according to the particular specification is more severe than in untreated wood. Mild steel and zinc-coated steel has been most susceptible. Stainless steel is hardly attacked at all.

Key words: Heat-treatment, thermal treatment, corrosion, fasteners, nails, screws

1. Introduction
The properties of the heat-treated wood in interaction with other materials is an important aspect of the performance of a construction of heat-treated wood and its overall durability. The aim of this study was to investigate the effect of heat-treated wood on different types of metal fasteners in comparison with untreated wood. The trial is part of a series of investigations of heat-treated wood that SP Swedish National Testing and Research Institute initiated in 2001 with financial support from the Swedish Wood Association (Jermer *et al* 2003). In this report results after two years' exposure outdoors are reported.

2. Material
The fasteners included in the test are described in Table 1. The areas have been calculated based on the nail and screw dimensions given and are considered as accurate as possible.

Table 1. Fasteners in corrosion trial with untreated and heat-treated wood.

Type of fastener	**Dim.**	**Material**	**Area** cm^2	**Supplier**
Nail Mild steel	50x2,0 mm	Steel quality CD9 (EN 10016-2)	4	Gunnebo Fastening AB
Nail Zinc coated steel (hot-dip galvanized)	50x2,0 mm	Steel quality CD9 (EN 10016-2) zinc coating > 50 µm	4	Gunnebo Fastening AB
Nail Stainless steel	50x2,0 mm	Steel quality A4 (SS 2347)	4	Gunnebo Fastening AB
Nail Aluminium	50x4,0 mm	Al-wire* (SS 4120)	6,5	Gunnebo Fastening AB
Screw ”Grabber” Sanbond Z-coated steel	42 mm (length)	Steel quality C1018; coating of nickel, zinc and chromate >16 µm	4	Arne Thuresson Byggmaterial AB

*Al 97,2 %, Mg 2,2-2,8 %, Cr+Mn 0,15-0,50 %

The wood used was spruce (*Picea abies*) from South-western Sweden. The heat-treatment was carried out in Finland according to the ThermoWood process at a maximum temperature of 220 °C during five hours. Today (2005) the ThermoWood process is performed at somewhat lower temperatures to reduce the effects of the heat treatment on the structural properties of the wood.

3. Methods

Each fastener was washed in ethanol and then weighed, before being applied to samples of 45x145x500 mm, standing upright as in figure 1. The fasteners are thus tangentially oriented in the wood sample. The trial set-up is a modified set-up used by Boliden AB in a trial carried out in the 1970s (Berglund, Wallin 1978). A sealing compound was applied between fasteners of different materials to prevent galvanic elements from arising if water remains on the horizontal surface.

At the first inspection after two years, two fasteners of each kind and each kind of wood were removed, and inspected visually. The rating was done according to Table 2. In addition to the visual inspection the metal loss (corrosion rate) was also calculated.

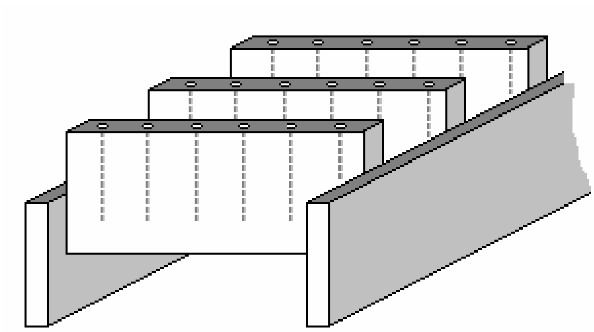

Figure 1. Sample set-up for corrosion testing.

Table 2. Assessment of corrosion attack.

Rating	Description	Definition
0	No attack	
1	Insignificant attack	<5 % of surface attacked
2	Slight attack	5-50 % of surface attacked
3	Serious attack	50-95 % of surface attacked
4	Completely attacked	>95 % of surface attacked

Attacks on both surface coating and the basic material were assessed using the same scale. The rating was then weighted using the following formula:

$$\text{Weighted rating} = \frac{\text{rating surface coating} + 3 \cdot \text{rating basic material}}{4}$$

The metal loss was calculated and expressed as metal loss per surface unit (g/m^2), and as depth of corrosion (µm).

In order to determine the metal loss and depth of corrosion the corrosion products had to be eliminated. Thus the fasteners were pickled, cleaned and then weighed. Pickling and cleaning were performed as follows:

1. Five minutes pickling in an ultrasonic bath
2. Two minutes cleaning in hot water in an ultrasonic bath
3. Ten seconds rinsing in hot running water
4. Drying with a clean paper tissue
5. Dipping for 30 seconds in 96 % ethanol
6. Drying with a clean paper tissue
7. Storage for at least one hour in a desiccator. To equalize the temperature, this was done in the same room as the weighing.

The pickling solutions used are specified in Table 3.

Table 3. Pickling solutions.

Metal/Surface treatment	**Temperature**	**Pickling solution**
Steel	25 °C	Clark's solution: Concentrated hydrochloric acid with an additive of 20 g/l antimony oxide and 20 g/l stannic chloride
Aluminium	80 °C	Chromic acid 20 g/l and phosphoric acid 50 ml/l de-ionized water
Zinc-coated and Sanbond Z-coated steel	25 °C	5 % acetic acid in de-ionized water

All fasteners were pickled, with the exception of the stainless steel nails. After pickling the fasteners were weighed and the weight loss calculated as the difference between the original weight (prior to exposure in the trial) and the weight after pickling.

Thus, the metal loss per surface unit was calculated accordingly:

$$\text{Metal loss (g/m}^2\text{)} = \frac{\text{Original weight (g) - Weight after pickling (g)}}{\text{Fastener area}\left(\text{m}^2\right)}$$

The depth of corrosion is another way of expressing the metal loss and means that the thickness of the lost metal layer is calculated according to the following formula:

$$\text{Depth of corrosion (µm)} = \frac{\text{Metal loss}\left(\text{g/m}^2\right)}{\text{Density}\left(\text{kg/dm}^3\right)}$$

The following densities were used:

Mild steel	7,8 kg/dm^3
Zinc-coated steel	7,1 kg/dm^3
Aluminium	2,7 kg/dm^3
Stainless steel	7,9 kg/dm^3

3. Results

Figure 2 shows examples of fasteners exposed in heat-treated and untreated wood. The result of the visual inspection is presented in Figure 3. Metal loss and depth of corrosion after two years' exposure are presented in Tables 4 and 5, and in Figure 4 the depth of corrosion is presented graphically.

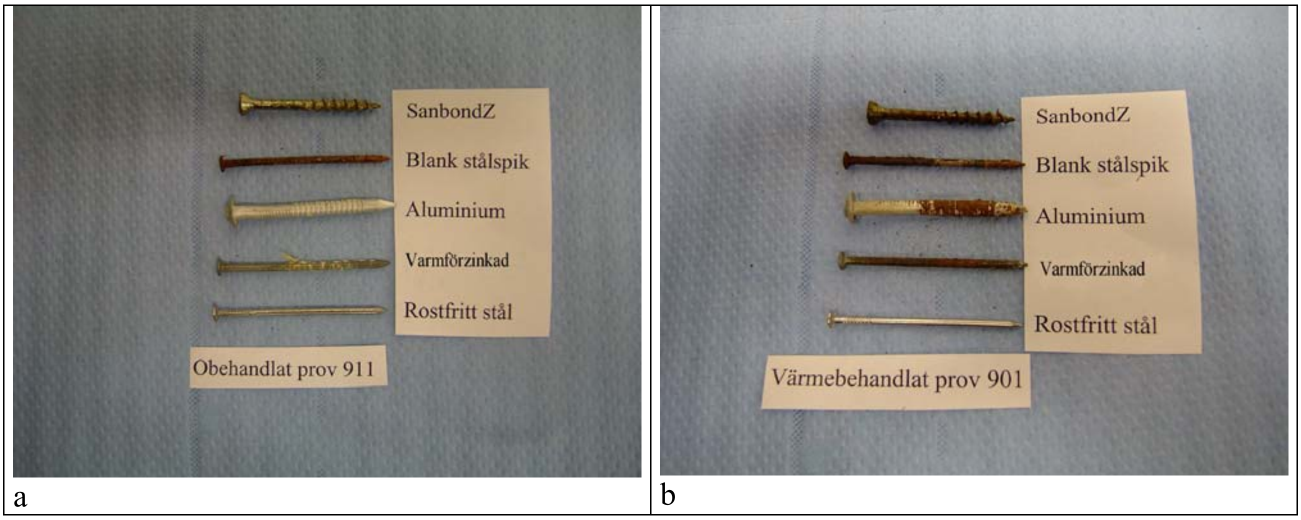

Figure 2. a) Fasteners exposed in untreated wood. b) Fasteners exposed in heat-treated wood

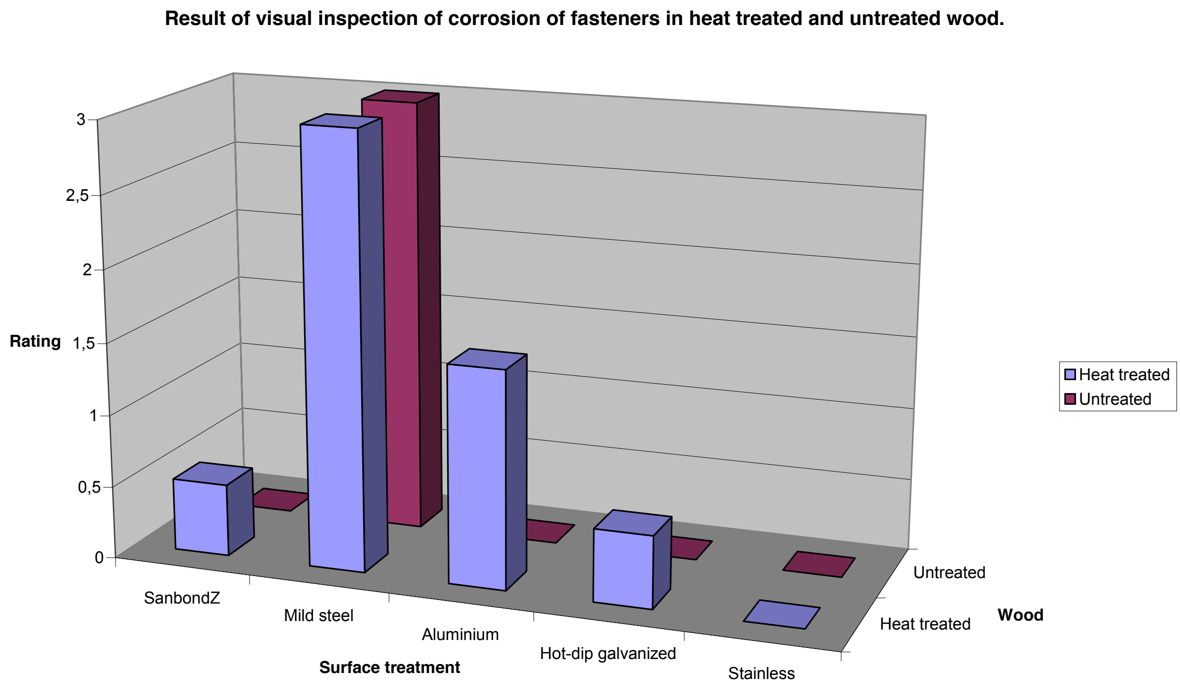

Figure 3. Result of visual inspection of corrosion of fasteners in heat-treated and untreated wood.

Table 4. Metal loss (g/m^2) of fasteners in heat treated and untreated wood after two years' exposure.

Fastener	Nail mild steel	Nail hot-dip galvanized steel	Nail stainless steel	Nail aluminium	Screw steel coated with Sanbond Z
Heat-treated	456	229	0	46	116
Untreated	188	34	0	23	49

Table 5. Depth of corrosion (μm) of fasteners in heat-treated and untreated wood after two years' exposure.

Fastener	Nail mild steel	Nail hot-dip galvanized steel	Nail stainless steel	Nail aluminium	Screw steel coated with Sanbond Z
Heat-treated	58	32	0	17	16
Untreated	24	5	0	8	7

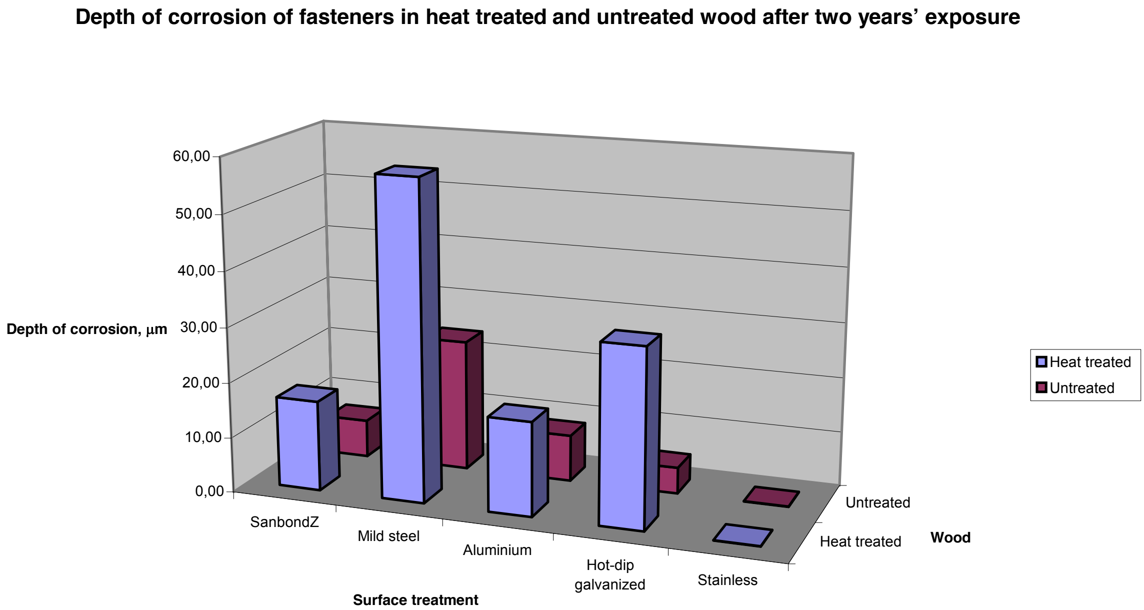

Figure 4. Depth of corrosion (μm) of fasteners in heat-treated and untreated wood after two years' exposure.

Stainless steel has performed best so far with basically no corrosion at all. Aluminium and Sanbond Z-coated steel has also performed fairly well, whereas mild steel has been severely attacked in the heat-treated wood. Hot-dip galvanized steel has, surprisingly enough, been quite attacked in the heat-treated wood already after two years' exposure.

There was a fairly good correlation between the results of the visual assessment and the calculated depth of corrosion. However, the actual corrosion found for hot-dip galvanized steel was more severe than found at the visual inspection.

4. Conclusions

Although only two fasteners of each kind have been examined and the time of exposure was only two years, it seems as heat-treated wood is more aggressive to all metals and coatings tested but stainless steel than untreated wood. A possible explanation is the existence of residual acids, mainly acetic and formic acids (Bourgois and Guyonnet 1988, Manninen et al 2002, Tjeerdsma et al 1998, Sundqvist 2004), that are formed during the heat treatment. It has to be pointed out that the results from this study may not be valid for heat-treated wood in general but so far only for heat-treated wood treated according to the particular process applied.

The next inspection is planned after five years' exposure.

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