The performance and documentation of Superwood

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1. Background and purpose

This report outlines the supercritical wood treatment process and the performance documentation of Superwood®.

2. Superwood and supercritical wood impregnation

Superwood is a brand name for wood (Norway Spruce (*Picea abies*)) treated with organic biocides using supercritical impregnation. The organic fungicides does not chemically alter the structure of the treated wood and therefore, 'Superwood' is not chemically modified wood, but simply spruce with added fungicides.

Norway spruce (*Picea abies*) is a conifer species native to Northern, Eastern, and Central Europe. Non-treated Norway spruce is classified as slightly to not durable (durability class 4-5) according to EN 350 (table 1). The percentage mass loss (ML) is found following testing according to EN 113-2:2020, which is similar, but not identical, to the EN 113-1:2020 test according to which Superwood has been tested with a resulting mass loss of ≤ 3 % (corresponding to durability class 1 in EN 350). The results of Superwoods EN 113-1 test are described in section 3.2 below.

Table 1. *Durability classes (DC) of wood to fungal attack (basidiomycete fungi). From EN 350.*

Durability class	Description	Percentage mass loss (ML)
DC1	Very durable	ML ≤ 5
DC2	Durable	5 < ML ≤ 10
DC3	Moderately durable	10 < ML ≤ 15
DC4	Slightly durable	15 < ML ≤ 30
DC5	Not durable	30 < ML
ML = highest of the median mass losses (in %) determined for test specimens exposed to each of the used test fungi		

Spruce has a closed cellular structure in the dried state, which means it is extremely difficult to treat with conventional pressure impregnation processes and impregnation with liquid solvents usually results in a shallow penetration of treatment fluids. Therefore, Norway spruce is rarely used for conventional pressure impregnation processes. Norway spruce can, however, be impregnated to the core using the supercritical impregnation process because of the unique properties of supercritical carbon dioxide explained below.

The supercritical wood impregnation process is different from traditional pressure impregnation processes because it uses supercritical CO_2 as carrier solvent instead of liquid solvents. Supercritical CO_2 is essentially a heavy gas that exists beyond the critical conditions for carbon dioxide (Figure 1).

Compared to conventional liquid pressure impregnation processes, the supercritical impregnation process uses a higher impregnation pressure and a different solvent (CO_2). However, the supercritical impregnation process can still be classified as a 'pressure impregnation process'.

Supercritical carbon dioxide has a combination of liquid and gas like properties that makes it an attractive solvent for wood impregnation purposes – both from and technical and environmental point of view. In an acknowledgement of the potential environmental benefits, Superwood was awarded the European Awards for the Environment in 2002. Like liquids, supercritical CO_2 has a high density allowing for dissolution of biocides. However, supercritical CO_2 has no surface tension and the viscosity is closer to that of gasses. Consequently, supercritical CO_2 penetrates wood easier than liquid solvents allowing for the impregnation of refractory wood species like Norway spruce, which are difficult to impregnate using liquid solvents.

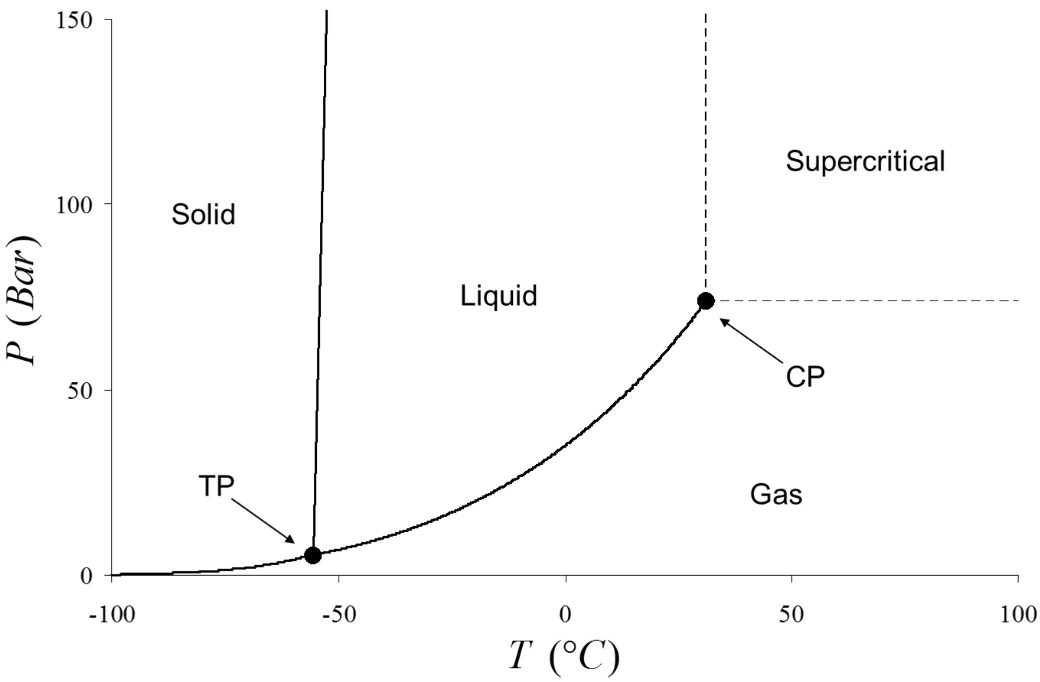

Figure 1. *Phase diagram of CO_2. CP: critical point. TP: triple point.*

Another feature, which separates the supercritical impregnation process from conventional liquid impregnation techniques, is that the process is a dry impregnation process. Being a gas, supercritical CO_2 does not wet the wood and the wood is dry before, during, and after impregnation. Because the wood is dry after impregnation, quality control of chemical uptake cannot be checked by simply weighing the wood, but has to be carried out by chemical analysis.

The wood preservative used by Superwood is called SC200 which contains a mixture of the fungicides tebuconazole, propiconazole, and IPBC.

3. Durability tests

3.1. Use class definition and required tests

The European Standard EN 335 defines use classes for different service situations relevant to solid wood and wood-based products (Table 2). The use classes are defined based on differences in environmental exposure that can make the wood or wood-based products susceptible to biological degradation. Superwood is intended for use class 2 and 3 (including both sub-class 3.1 and 3.2), i.e. wood exposed outside above ground exposed to the weather (not covered) or under cover with risk of wetting or condensation.

Table 2. *Use classes defined by EN335.*

Use Class	Environmental exposure	Superwood's relevance
1	Inside a construction Dry	Not relevant (impregnated wood not necessary inside)
2	Above ground, outside Under cover, risk of wetting and condensation	Relevant
3	Above ground, outside Exposed to weather	Relevant
Sub-class 3.1	Situations without prolonged wetting (no water accumulation)	Relevant
Sub-class 3.2	Situations with prolonged wetting (water accumulation).	Relevant
4	Contact with ground and/or fresh water	Not relevant
5	Contact with salt water (marine environment)	Not relevant

The European Standard EN 599-1 specifies the biological tests required for evaluating the efficacy of wood preservatives for each of the use classes defined by EN 335. The test regime required for evaluating the efficacy of wood preservatives for use class 3 is shown in table 3. For use class 3, EN 599 specifies laboratory testing (EN 113), where the principle is to determine the critical values of the actives against biological attack (brown rot, white rot and soft rot). Furthermore, additional field tests can be carried out e.g. EN 330, L-joint.

In agreement with the EU Biocidal Product Regulation (BPR), it is a requirement for registering and bringing fungicidal products on the market, that the efficacy of the product has been evaluated according to the required tests specified in EN 599 and that the critical value of the product has been determined.

Table 3. *Performance criteria in biological tests for hazard class 3, (penetrating processes).*

Requirement	Min. requirement for fungal/field tests			Additional/local tests		
	With or without coatings	Only under coatings				
	Basidiomycetes	Basidiomycetes	Field test	Field test	V	B
Test	EN 113 Without (V)	EN 113 Without (V)	EN 330	EN 330	EN 113 (with V)	EN 152-2
Ageing	EN 73, EN 84 (Separately)	EN 73	No additional ageing according to laboratory method	No additional ageing according to laboratory method	EN 73, EN 84 (Separately)	EN 152-2
(V) *Coriolus versicolor*						
(B) Blue stain						

Superwood has been tested according to EN 599-1 for use class 3. This involves laboratory testing to determine the critical value against basidiomycetes (wood degrading fungi) according to EN 113, also after accelerated ageing by evaporation (EN 73) and leaching (EN 84). Additional laboratory tests have been performed documenting the performance against bluestain (EN 152). Furthermore, additional field tests (EN 330, L-joint) have been carried out in order to document its performance in field exposure scenarios. The extent of biocide leaching has been determined through a semi-field test study.

The results of the testing is summarized below. Full test reports are on file at Superwood.

3.2. EN 113 (Laboratory determination of biocidal efficacy)

The purpose of the EN 113-1 is to assess the biocidal efficacy of wood preservatives by determining the critical value against wood destroying fungi.

The critical values (i.e. the concentration of fungicide which is sufficient to provide adequate protection against wood-destroying fungi) were determined for SC200 using EN 113 as a stand alone test, and by using EN 113 after accelerated ageing according to EN 73 (evaporation) and EN 84 (leaching). The tests were performed by MPA in Eberswalde (MPA 2002a-c).

Principle of the test
EN 113
Test samples of Scots pine sapwood are impregnated with a range of concentrations of the preservative product (SC200). The test samples are then subjected to attack from wood-destroying fungi cultured on an agar medium. Test duration is 12 weeks after which the test samples are removed and the mass loss determined. The critical values are defined as the concentration of fungicide where the weight loss after exposure to wood destroying fungi is less than 3%. The test is often carried out on samples which have been subjected to accelerated ageing procedures according to EN 73 and EN 84.

EN 73
The impregnated test samples are placed in a wind tunnel at 40°C for 12 weeks prior to the EN 113 test.

EN 84
The test samples are subjected to a leaching procedure consisting of an initial vacuum impregnation with water followed by submersion in water for two weeks during which the water is changed 9 times. The test samples are then subjected to the EN 113 test.

Results
An overview of the results for SC200 is presented in Table 4. SC200 was tested against three brown rot fungi, *Coniophora puteana*, *Poria placenta*, and *Gloeophyllum trabeum*. Based on the EN 113 test, MPA Eberswalde concluded that the critical value for SC200 is 60 g/m^3 when tested according to EN 113 alone, and 120 g/m^3 when tested according to EN 113 + EN 73 and EN 113 + EN 84.

Table 4. *Results of the EN113 test (g/m^3) for SC200.*

Name of test fungus	*Coniophora puteana*			*Poria placenta*			*Gloeophyllum trabeum*		
Test	EN 113	EN 113/73	EN 113/84	EN 113	EN 113/73	EN 113/84	EN 113	EN 113/73	EN 113/84
Critical value (g/m^3)	60	120	120	60	120	60	60	60	120

3.3. EN 330 (Field test, L-joint)

A field test of Superwood according to EN 330 has been conducted under tropical conditions in Malaysia from 2004 to 2009 (Figure 2). SC200 was tested on supercritical impregnated spruce (Superwood) at a concentration of 160 g/m^3 and on supercritical impregnated pine sapwood at 120 g/m^3, 160 g/m^3, and 250 g/m^3.

The performance of the treated samples was compared to samples treated with GORI 356 (flow coat) and GORI TH 92 (double vacuum) containing the same actives as SC200 namely propiconazole, tebuconazole and IPBC. However, the ratio between the actives is slightly different for the different products. For GORI 356 and GORI TH 92 the ratio between tebuconazole, propiconazole, IPBC is 3:1:1 while the ratio for SC200 is 2:2:1. Samples of TBTO (standard reference) and heat treated pine were also included in the test.

EN 330 is considered an additional test according to EN 599-1 and is especially suitable for surface coated preservative treated wood. The field test was set up at UNIMAS (University of Malaysia, Sarawak). The Danish Technological Institute examines the acceleration factor when comparing degradation in tropical Malaysia with degradation in temperate Denmark. From these studies an accelerated degradation by a factor of up to 5 is expected.

Figure 2. *L-joints exposed in Malaysia. Photo: DTI.*

Principle of the L-joint test

Jointed samples (L-joints) are treated, assembled, and coated. After the coating is completely dry, the L-joints are taken apart so that the coating is broken across the L-joint itself. The L-joints are then reassembled and placed outdoors, out of ground contact and exposed to normal environmental factors. The broken coating at the joint creates a water trap, which accelerates fungal colonization and the natural breakdown of the sample. The fungi that colonize such units invade in their natural sequence of molds, blue stain fungi, soft rot fungi and *Basidiomycetes*. Colonization by *Basidiomycetes*, as shown by the presence of visible decay is assessed at least annually by visual inspection of the L-joints after being disassembled. In addition, periodically, sets of samples are examined after sawing to reveal their internal condition. These data are compared with those generated using reference preservative(s) and untreated samples to assess relative performance. The rating system used for evaluation is given in table 5.

Table 5. *Rating system used for evaluation of decay in L-joints.*

Rating	Description	Definition
0	Sound	No evidence of deterioration
1	Slight attack	Slight discoloration, often dark and in streaks; no significant softening or weakening of the wood
2	Moderate attack	Distinct discoloration, but in discrete patches and streaks, with small areas of decay (softened, weakened wood); typically no more than 25% of the visible area affected
3	Severe attack	Marked softening and weakening of the wood typical of fungal decay and in extensive patches or streaks; distinctly more than 25% of the visible area affected
4	Failure	Very severe and extensive rot; Tenon often capable of being easily broken

Results
The final evaluation of the L-joint test was done in 2009 (DTI 2010). The results are given in table 6. The conclusion of the test was that SC200 impregnated spruce, with a rating of 1.4, performed equally as well as the internal standards GORI TH 92 (1.2) and GORI 356 (1.3). The standard reference, 2% TBTO, was severely attacked (3.6) and the untreated pine sapwood samples had completely failed (4.0). Untreated pine heartwood (1.7) performed quite well and only a slight improvement was seen by impregnation of heartwood with SC200 (1.4). Heat treated pine sapwood performed with varying results approaching severe attack as mean (2.7). SC200 treated pine sapwood also performed with varying results (2.2-3.4) and the treatments were moderately to severely attacked. No clear dose response could be seen from 0.12-0.3 kg/m^3.

Table 6. *Results from the L-joint test after 5 years exposure in Malaysia.*

Treatment	Retention (kg/m^3)		Malyasia 5 years
	Tenons	Mortises	Rating
SC200 spruce	0.16	0.16	1.4
SC200 pine sap	0.12	0.12	2.8
SC200 pine sap	0.16	0.16	2.2
SC200 pine sap	0.3	0.3	3.4
SC200 pine heart	0.16	0.16	1.4
GORI TH92 pine sap	30.7 product	30.3 product	1.2
GORI 356 pine sap	183 g/m^2	183 g/m^2	1.3
Heat treated pine	-	-	2.7
TBTO pine sap	25.7 product	27.0 product	3.6
Untreated pine sap	-	-	4.0
Untreated pine heart	-	-	1.7

3.4. Additional field test with the obsolete SC100 wood preservative

In 2002, a field test involving supercritical impregnated wood (SC100) was set up in Norway at the Norwegian Forest and Landscape Institute. SC100 contains the same mixture of the fungicides as SC200 (tebuconazole, propiconazole, and IPBC) but in a different relation (3:1:1 for SC100 and 2:2:1 for SC200). SC100 is no longer used by Superwood. The purpose of the field test was to document the performance of a number of different treated and non-treated woods against wood destroying fungi. The test was set up as a ground proximity tests, where the treated wood pieces are placed directly on the ground which increases the rate of fungal attack. The results were presented at an International wood protection conference in 2013 (Schabacker et al. 2013). The below table show the test results from non-surface treated samples. Supercritical impregnated wood performed in the top end of the 17 treated and non-treated types of wood in the study (Table 7).

Table 7. *Decay ratings for different types of treated and non-treated wood without coating in the sited field test.*

Ranking No.	Top layer: Treatment	Decay rating	Ranking No.	Core layers: Treatment	Decay rating	Ranking No.	Bottom layer: Treatment	Decay rating
1	Gori SC 100	0.5	1	Gori SC 100	0.0	1	Royalimp clear	1.0
2	ACQ 1900	1.0	2	Styren	1.0	1	Royalimp pigm.	1.0
3	Styren	1.0	2	Royalimp pigm.	1.0	1	Gori SC 100	1.0
3	Tanalith E7	1.0	2	Tanalith E7	1.0	4	Wolmanit CX-8	1.5
3	Royalimp pigm.	1.0	2	Wolmanit CX-8	1.0	5	ACQ 1900	2.0
3	Larch heart-wood	1.0	2	Royalimp clear	1.0	6	Styren	2.0
3	Thermal mod.	1.0	2	Tanalith M (color)	1.0	6	Tanalith E7	2.0
3	Tanalith M (color)	1.0	2	Gori Pres 10	1.0	6	Furfurylation	2.0
3	Gori Pres 10	1.0	9	Tanalith M	1.2	6	Tanalith M (color)	2.0
3	Scanimp	1.0	10	Scanimp	1.3	6	Scanimp	2.0
11	Wolmanit CX-8	1.5	11	Larch heart-wood	1.3	6	Gori Pres 10	2.0
11	Royalimp clear	1.5	12	ACQ 1900	1.5	12	Larch heartwood	2.5
11	Tanalith M	1.5	13	Furfurylation	2.2	13	Tanalith M	3.0
14	Pine heart-wood	2.5	14	Thermal mod.	2.8	13	Thermal mod.	3.0
15	Furfurylation	3.0	15	Pine heartwood	3.0	15	Pine heartwood	3.5
16	UltraWood	3.5	16	UltraWood	3.2	16	UltraWood	4.0
16	Pine Sapwood	3.5	17	Pine Sapwood	3.8	16	Pine Sapwood	4.0

3.5. EN 152 (Laboratory test, Blue stain)

The resistance of Superwood against blue stain was tested according to EN 152. EN 152 is considered an additional test according to EN 599-1.

Principle of the Test
The principle of the test is to provide the conditions for infection by blue-stain fungi and observe the development of infection. Treatments according to the specified methods are applied to “treatment sticks”, from which the treated test panels are subsequently cut. The sticks are exposed to natural weathering for 6 months in the period between March and October. Afterwards, the specimens are exposed to a culture of blue stain fungi in the laboratory. A comparison of the extent of blue staining of the test samples with untreated control shows the effectiveness of the test product. The specimens are examined for blue stain on the surface according to the following rating 0, 1, 2 and 3. The rating 0 is no occurrence of blue stain, whereas 3 is severe attack of blue stain. The specimens are cut and the blue stain free zone is determined. The standard contains no approval requirements. EN 599-1 requires a zone free of blue stain of minimum 1.0 mm and in average 1.5 mm and no individual rating ≥ 2.

Results
The tested systems are presented in table 8 together with the results of the test (DTI 2005). System 1 had no blue stain on the surface. System 2 and 3 had a surface blue stain rating of 2 and a smallest depth of blue stain free zone of 5.0 mm, which was comparable to the reference with fungicide.

Table 8. *Test results from the blue stain test (EN 152) involving supercritical impregnated wood.*

System	Treatment	Top-coat	Blue stain rating on surface (average)	Smallest depth of blue stain-free zone, mm	Mean depth of blue stain-free zone, mm
System 1	0.16 kg/m^3 SC200	GORI 410 – 10210 + Gori 890 - 12210	0	4.5	5.0
System 2	0.16 kg/m^3 SC200	Standard Alkyd (GORI 90, Farblos 9900)	2	4.5	5.0
System 3	0.30 kg/m^3 SC200	Standard Alkyd (GORI 90, Farblos 9900)	2	5.0	5.0
Reference, top with fungicide	-	Standard Alkyd (GORI 90, Farblos 9900)	2	1.0	1.5
Reference with fungicide	Bondex Holzschutz-grund, Farblos	Standard Alkyd (GORI 90, Farblos 9900)	2	4.0	6.5
Reference without fungicide	-	50% linseed oil / 50% white spirit	3	0.0	0.0
Untreated control, with weathering	-	-	3	0.0	0.0
Untreated control, without weathering	-	-	3	0.0	0.0

4. Fire performance

Superwood can be used for cladding in many configurations. In some façade configurations there are demands in relation to Reaction to Fire and fire protection.

Solid untreated wood with sufficient density and restricted surface can obtain classification as D-s2,d0 (reaction to fire) and/or classified as a fire protecting system $K_1$10, D-s2,d0, without further testing, according to Commission Decision 2000/147/EC[1], if the cladding has a density larger than 390 kg/m^3 and certain geometries are fulfilled, such as minimum thickness and a profiled surface less than 20% larger than the exposed covered area and maximum 25% larger than of both exposed and not exposed areas.

Superwood is not directly covered by the Commission Decision as the wood is impregnated. The effect of the impregnation on the fire performance of Superwood cladding systems has therefore been tested. Superwood products (claddings) have been tested at accredited fire laboratories (DBI and Meka) to define Reaction to Fire and the fire protection class.

4.1. Superwood without surface coating

Fire tests, according to EN 13823 (Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item) and EN ISO 11925-2 (Reaction

[1] Commission Decision 2000/147/EC to DS/EN14915:2013+A2:2020 and CWFT (EU's Classification Without Further Testing), L349, dated 5.12.2014

to fire tests – Ignitability of products subjected to direct impingement of flame – Part 2: Single flame source test), performed both by DBI and Meka show that Superwoods impregnation process does not have negative influence on the impregnated wood and that Superwood cladding with a surface degree larger than 125% can obtain D-s2,d0 (classification according to EN 13501-1). Further tests with a surface degree of up to 145%, performed by DBI show that claddings with a surface degree lower than 145% can be classified as $K_1$10 D-s2,d0 (classification according to EN 13501-1). These results do not cover surface coated claddings – see section 4.2.

4.2. Superwood with surface coating

Superwood is available from the manufacturer with surface coating (paint) in various colors. Preliminary fire tests according to EN 13823, performed by Meka, have shown that some surface coatings contribute to the fire load. To ensure that pre-painted Superwood cladding systems fulfill requirements to Reaction to Fire, additional fire performance tests have been done by Meka, according to EN 13823, showing that painted cladding (in any color) with up to 151% surface degree and tongue and groove fulfill D-s2,d0 (classification according to EN 13501-1). This test covers all solutions with surface degree up to 151% with the same kind of paint as tested.

5. Corrosion test of fasteners in Superwood

A corrosion test was performed on fasteners in Superwood (ITW 2008). The test was done by ITW Construction Products ApS as a 2000 hour salt spray test according to EN 9227. The fasteners tested were NKT Climate®-X and MULTI+. Climate®-X is a steel fastener with a Climate®-X surface; MULTI+ is a stainless steel fastener. The conclusion of the test was that Superwood was neutral (no influence) on the corrosion of both Climate®-X and MULTI+ fasteners.

6. Authorization and quality control

6.1. BPR authorization

In order to market a wood preservative in the EU, the product must be authorized by the relevant environmental authorities according to the BPR, Biocidal Product Regulation (EU 2012). To obtain authorization, documentation must be submitted related to the environmental impact of the product and its efficacy against wood destroying fungi. The environmental impact assessment includes an assessment of the environmental impact of leaching of fungicides from the treated products in service. For the efficacy assessment, the EN 599-1 lays down the requirements for efficacy (see section 4.1).

SC200 has been authorized according to the BPR by the Danish Environmental Protection Agency with BPR registration number 674-1 (EPA 2012). According to the registration, the product is authorized for use as a wood preservative for use class 2 and 3 and can be used for impregnation against wood destroying fungi at a concentration of 120 g/m^3, and against blue stain and wood destroying fungi at a concentration of 160 g/m^3.

6.2. CE Mark

Superwood, with and without surface treatment, is CE marked according to EN14915. The performance declarations (DOPs) are available for download at www.superwood.dk.

6.3. External quality control

The Danish Technological Institute (DTI) checks the concentration of fungicides in Superwood bi-annually according to penetration class NP5 (EN 351-1). The concentration is checked by chemical analysis of wood samples picked randomly from the Superwood production site by DTI. DTI has performed the quality control since 2006 and the control is still ongoing.

7. Environmental aspects and certification

7.1. PEFC

Superwood is PEFC chain-of-custody certified with certificate registration code SA-PEFC/COC-007725. The validity of the certificate can be verified by checking the PEFC database: www.pefc.org. The current certificate is valid until the renewal date 10 September 2025.

7.2. Environmental Product Declarations (EPD)

Superwood has EPD's for the following products. The EPD's have been made in accordance with ISO 14025 and EN 15804 +A2 and based on the product category rules: NPCR Part A: 2021 Construction products and services Ver 2, and NPCR 015 Part B for wood and wood-based products 4.0. The EPD's have been published by the Norwegian EPD foundation and are available for download at www.superwood.dk.

Product	Declaration number	Valid to
Superwood without surface treatment	NEPD-3703-2649-EN	14.09.2027
Superwood surface treated once (transparent coating)	NEPD-3704-2649-EN	14.09.2027
Superwood surface treated twice (non-transparent coating)	NEPD-3705-2649-EN	14.09.2027

7.3. Cradle-to-cradle certification

Superwood is Cradle to Cradle Certified® with the rating 'Gold' for Superwood without surface coating (certification number: 4873), and the rating 'Bronze' for Superwood with surface coating (certification number: 4875). The certificates are valid until 17 AUG 2023 and are currently under renewal. The validity of the certificates can be checked at https://c2ccertified.org/certified-products.

7.4. Working environment

According to Danish legislation, the occupational exposure limit value for wood dust in the air is 1 mg/m^3 (BEK 2011). Dansk Toksikologi Center (Danish Toxicology Center), examined whether inhalation of dust from SC200 impregnated wood would lead to an increased health risk compared to inhalation of dust from non-treated wood (DTC 2004). The report concluded that dust from SC200 impregnated wood did not present an increased health risk compared to dust from non-treated wood and, consequently, the occupational exposure limit value of 1 mg/m^3 is sufficient to protect workers from risk.

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