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ANALYSIS OF A HYDROPHOBIC COATING AS PASSIVE ANTI-ICE SOLUTION FOR WIND TURBINES

Bachelor’s thesis 2013

ABSTRACT

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The future of energy production lies in renewable energy sources, and one of them is wind power. However, cold climates around the world are quite challenging when it comes to harnessing the wind for power production. The icing of turbine blades and anemometers often bring turbines to a grinding halt, which of course leads to significant production losses. Possible solutions for this problem include active and passive approaches.

In this thesis, a new hydrophobic coating that could work as a passive anti-ice solution for wind turbine applications was analyzed. Actual anti-ice properties could not be investigated due to lack of requisite equipment, but a number of mechanical properties also important for assessing the functionality of the coating were studied. In addition, surface drying times at a constant temperature and different levels of humidity were determined to learn more about the curing behavior of the coating.

Testing was carried out both on-site on a 1 MW turbine situated in Kotka, Finland as well as under laboratory conditions. The on-site testing involved the coating of test areas on turbine blades and subsequent inspections, and the laboratory testing followed procedures described in international standards as closely as possible.

The results showed a very good performance of the coating in terms of material properties such as adhesion, film hardness and dirt repelling tested in this study. This contributes to the completion of the material database and encourages to the execution of further testing to create a version of the coating that is fully employable on wind turbines.

TIIVISTELMÄ

KYMENLAAKSON AMMATTIKORKEAKOULU
Venealan koulutusohjelma

SKORCZEWSKI, JAN	Hydrofobisen tuulivoimaloiden jäätymisenestomaalin analysointi
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Uusiutuvat energianlähteet ovat energiantuotannon tulevaisuus, ja tuulivoima kuuluu samaan joukkoon. Kylmät ilmastot ympäri maailmaa kuitenkin asettavat omat haasteensa tuulivoiman hyödyntämiselle. Siipien ja anemometrien jäätyminen aiheuttaa usein merkittäviä tuotannon menetyksiä, sillä se voi johtaa tuulivoimalan pysähtymiseen. Ongelman mahdollisiin ratkaisumalleihin kuuluu sekä aktiivisia että passiivisia lähestymistapoja.

Opinnäytetyössä analysoitiin uudenlaista hydrofobista pinnoitetta, joka voisi toimia passiivisena jäätymisenestoratkaisuna tuulivoimasovelluksissa. Tarvittavien laitteiden puuttumisen takia varsinaisia jäätymisenesto-ominaisuuksia ei voitu tutkia, mutta muutamia pinnoitteen toimivuuden arvioimiselle tärkeitä mekaanisia ominaisuuksia tarkastettiin. Lisäksi määritettiin pintakuivumisaikoja vakiolämpötilalla ja eri ilmankosteusprosenteilla, jotta voitaisiin saada lisätietoja pinnoitteen kuivumiskäyttäytymisestä.

Testaus tapahtui sekä 1 MW:n tuulivoimalalla Kotkassa että laboratorio-olosuhteissa. Kenttäkokeessa pinnoitettiin koealueita voimalan siivistä, ja niitä käytiin myöhemmin tarkastamassa kaksi kertaa. Laboratoriokokeet seurasivat mahdollisimman tarkasti kansainvälisissä standardeissa kuvattuja menettelyjä.

Tulokset osoittivat pinnoitteen toimivan erittäin hyvin materiaaliominaisuuksien, kuten adheesion, kalvokovuuden ja lianhylkivyyden, suhteen. Tämä edistää materiaalitietopankin täydentämistä ja kannustaa suorittamaan lisää testejä pinnoitteen kaupallisen version kehittämiseksi tuulivoimasovelluksiin sopivaksi.

Contents

1 FOREWORD

Wind energy in areas with cold climates, as for example the Nordic countries, is for many reasons still a much-disputed topic. Winters are long and cold and ice build-up during icing conditions significantly reduces the efficiency of the turbines by distorting blade aerodynamics and can even pose a threat to people, wildlife and structures in the direct vicinity of the turbine because of ice throw. Also mechanical stresses on the turbines resulting from asymmetric ice accumulation and failing lubrication in low temperatures or problems with electrical components have to be taken into account. Ice loads and deteriorating material properties due to low temperatures can cause premature fatigue. Another factor is snow that, carried by the wind through ventilation openings into the nacelle of a turbine, can damage all electrical equipment.

Mechanical de-icing of turbine blades and cleaning of the nacelles by maintenance personnel can be extremely challenging and costly particularly in remote areas, when reaching the sites with all the equipment needed is leastways arduous due to snow.
Still there are many areas in countries with cold climates that offer good wind conditions to be harnessed for energy production especially in winter, and despite all aforementioned drawbacks, the Nordic countries for example have for some years been increasing their ratio of annual wind-generated energy to total energy production.

The Finnish wind power production reached a total of 483 GWh by the end of 2011, generated by 131 wind turbines. This was at that time only approximately 0.6 % of total annual national electric power consumption. Still, comparing installed wind power capacity in Finland in the year 2000 (38 MW) to installed wind power capacity in June 2012 (220 MW, 137 turbines), one can see a quite significant increase of almost 480 %. [1]

Significant are also plans of Finnish government, introduced in 2008 and upheld in 2010, to raise installed capacity to 2500 MW (6 TWh production) until 2020. This would mean an estimate total of over 800 wind turbines. [2] The Danish wind-industry consulting company BTM, however, is a little less optimistic about these figures, but still considers just under 1000 MW of installed capacity until 2016 to be realistic [3].

Danish wind-generated electricity corresponded to as much as 32 % of national power consumption in 2012, although it is partly exported to neighbouring countries due to excess production at certain times. The Danish government recently adopted plans to increase wind power percentage to even 50 % by 2020.

Already by now Denmark has the highest ratio of wind-generated power to power demand in Europe. [4] There are more than 5000 wind turbines installed in Denmark [5].

Looking at the corresponding figures for the other Nordic countries, Sweden produced around 3.5 TWh, which represents about 2.2 % of its total electric consumption, by wind turbines in 2010 (2019 MW installed, 1655 turbines) [6]. Norwegian wind turbines (525 MW installed) produced 1.2 - 1.3 TWh annually by the end of 2011, which equates to around 1 % of power consumption in Norway [7].

All in all we are looking at a total of over 7000 wind turbines in the Nordic countries alone, and figures are growing.

Having examined these numbers, one can easily understand the importance of keeping cost intensive downtime of wind turbines due to severe icing and resulting maintenance procedures low. Focusing on the turbines’ rotor blades, a number of different solutions for anti-icing or de-icing have already been introduced to the market, but the quest for the optimum solution is still ongoing. A quick explanation of terminology: anti-icing is the prevention of ice accumulation, while de-icing describes the active removal of ice on the blades respectively.

The solutions mentioned above include active and passive approaches. State-of-the-art active solutions are either electro thermal heating elements on or close to the surface of the blades or warm air circulation systems heating the blades from inside. Other applications such as microwave heating have been discussed but are not available yet.

Hydrophobic, superhydrophobic, or ice-phobic coatings represent possible passive solutions. However, hydrophobicity will not guarantee that ice will not adhere to the surface. On the other hand, it will increase the efficiency of blade heating and reduce dirt adhesion during above-zero temperatures. [8] Also, ice-phobic coatings are not necessarily preventing ice build-up, but weaken the binding between ice and surface to an extent that makes it much easier to remove the ice [9].

A perfectly working passive solution would be a revolutionary breakthrough for the wind energy sector, as it would be much more cost effective than active or combined systems owing to zero energy consumption, virtually no possibility of failure and low maintenance costs. In addition, a passive anti-icing solution in form of a coating would enable wind turbine operators to upgrade already working turbines in cold climates for ice-free operation with little effort.

This Bachelor’s thesis examines applicability and material properties of a new hydrophobic coating, NWE SALES Nordic Anti-Friction Silane, which is meant to work as a passive anti-ice coating for wind turbine blades. The assessment of the coating properties is done by executing both material tests under laboratory conditions as well as on-site testing on the blades of a 1 MW wind turbine, situated directly at the shoreline in Kotka on the south coast of Finland.

The thesis was completed as part of the multiregional RENEWTECH project which started in August 2011 and concentrates on the development of wind power technologies and related business operations in Southern Finland. Project partners are CURSOR Ltd, North European Logistic Institute (NELI), the Lappeenranta University of Technology, the Kymenlaakso University of Applied Sciences (KyAMK), Lappeenranta Innovation (LPRINNO) and Etelä-Kymenlaakso Vocational College (EKAMI). The project is due to be completed by the end of 2013. [10] Direct client for this work was the Kymenlaakso University of Applied Sciences with Senior Lecturer and Energy Engineering Program Director Markku Huhtinen in the role of the RENEWTECH project contact person. Supervising teacher was Development Engineer Mikko Pitkäaho of Kymenlaakso University of Applied Sciences.

Participation at the international Winterwind conference in Skellefteå, Sweden, in February 2012 proved to be very helpful in obtaining background information and an insight into where wind energy in cold climates is standing at today. It also contributed to the decision to write this thesis in English because of possible international interest, together with the fact that the author’s native language is not Finnish.

2 THE COATING

2.1 Mechanical and chemical properties[1]

NWE SALES Nordic Anti-Friction Silane is a solvent free epoxy silane based hybrid resin, which has been nanomodified for improved performance. Generally speaking, modification at nanoscale is carried out at dimensions less than a billionth of a metre. The coating is extremely slick and hydrophobic and will adhere to different composite materials, metals and concrete. The slickness of the surface also makes it easy to clean and it displays high gloss, low surface tension and a smooth, non-porous ceramic surface. Tests conducted earlier, considering the impact of weather and different chemicals on the paint, revealed its excellent durability. The coating forms a protective friction-reducing surface with good UV resistance and low yellowing. Other properties important for rotor blade applications are Nordic AFR’s resistance to salt water, easy application with conventional spraying equipment and long gloss retention. Furthermore the coating needs no post-curing and reaches its final hardness even at temperatures below +10° Celsius.
The coating is available in white, grey and black, has a relative weight of 1.5 kg per litre and can be removed with ethanol or acetone while in fluid state. Once cured, it has to be removed mechanically. No observation of thermoplasticity could be made up to temperatures exceeding 200° Celsius.

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[1] All information provided by NWE SALES

2.2 Safety data sheet information[2]

Safety data sheet information classifies the coating as harmful (Xn) and dangerous to the environment (N).

Chemical risk- and safety phrases:

- R36/38 Irritating to eyes and skin
- R43 May cause sensitisation by skin contact.
- R51/53 Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
- R68 Possible risk of irreversible effects.
- S24 Avoid contact with skin.
- S26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
- S28 In case of contact with skin, wash immediately with plenty of neutral soap.
- S29 Do not empty into drains.
- S36/37 Wear suitable protective clothing and gloves.

2.3 References[2]

Reference applications and other target applications include:

- traffic signs (Finnish Transport Agency)
- fast patrol boats (Royal Norwegian Navy)
- process manufacturing/thermal power plants (TeKe Ltd.)
- wind turbine coatings
- anti-graffiti coatings
- tile coatings
- commercial transport coatings
- offshore/marine coatings
- pipe lining coatings

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[2] All information provided by NWE SALES

- structural steel protection
- rail car and tank construction

3 ON-SITE TESTING ON TURBINE “ILONA”

3.1 Coating of the test areas

3.1.1 Purpose

Due to deteriorating weather conditions causing lack of time to perform laboratory testing or any other way of approach to this thesis earlier, the coating of test areas on the blades of the 1 MW wind turbine “Ilona” in Kotka, Finland (60°25'34.38"N, 26°53'4.79"E), was executed on December 1st, 2011 and initiated work on the thesis. “Ilona” is a Bonus turbine with a tower height of 60 m and a rotor diameter of 54,2 m. Power production begins at wind speeds of 3 m/s and stops at 25 m/s. Optimum wind speed is 15 m/s. [11]

Actual field-testing of the coating was the first step taken for this study.

The main motive of field-testing NWE SALES Nordic Anti-Friction Silane was to get an impression of some of the coating’s properties, such as adhesion, cohesion, cure and finish, under target application conditions.

The personnel on the execution of the test coating consisted of 3 employees of Kotka Energy responsible for stopping the turbine and turning the blades into the desired position, Chairman of the Board Kimmo Kaila of NWE Sales delivering the coating, the skylift operator of Janneniska Ltd., Lead Composite Engineer Andrew Passey of Bladefence for conducting the actual coating, Development Engineer Mikko Pitkäaho of Kymenlaakso University of Applied Sciences and the author of this thesis himself.

3.1.2 Weather conditions

The components of the paint had been mixed together one hour before application and kept warm at a temperature of around 17 degrees Celsius to ensure appropriate material viscosity. Weather conditions during the beginning of coating of blade 1 (around 10 a.m.) represented figures from the lowest sector of the application temperature range:

air temperature	+5° Celsius
blade surface temperature	+7° Celsius, sun facing side
	+2° Celsius, shady side
wind speed	5,5 m/s
humidity	87 %

Conditions had improved slightly when work on blade 2 was commenced starting from 12 p.m. Development of the weather conditions during the coating process can be followed from the subsequent diagrams 1 - 5. All weather data except the amount of precipitation, shown in diagram 5, were recorded at the weather station of Rankki, an island approximately 7 kilometres southeast of wind turbine “Ilona”. The data presented in diagram 5 were recorded at Kirkonmaa weather station, an island approximately 8 kilometres southeast of the turbine.

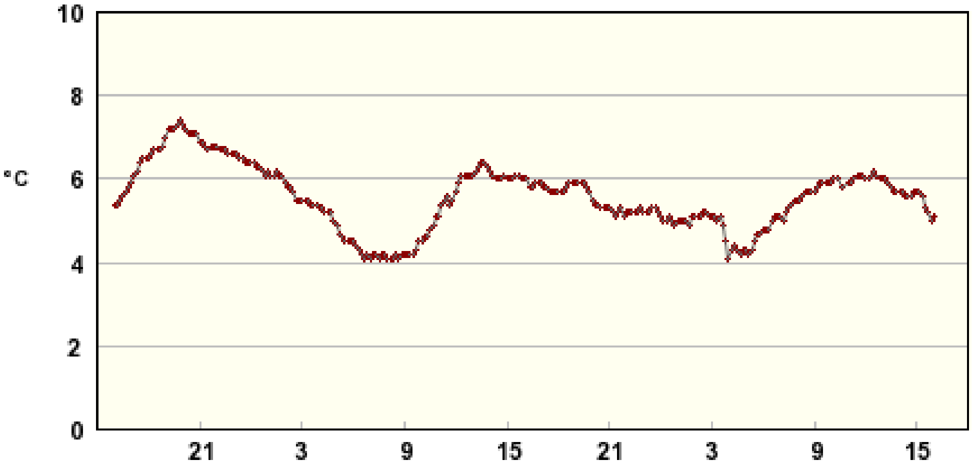


Diagram 1. Temperature from November 30th, afternoon to December 2nd, afternoon

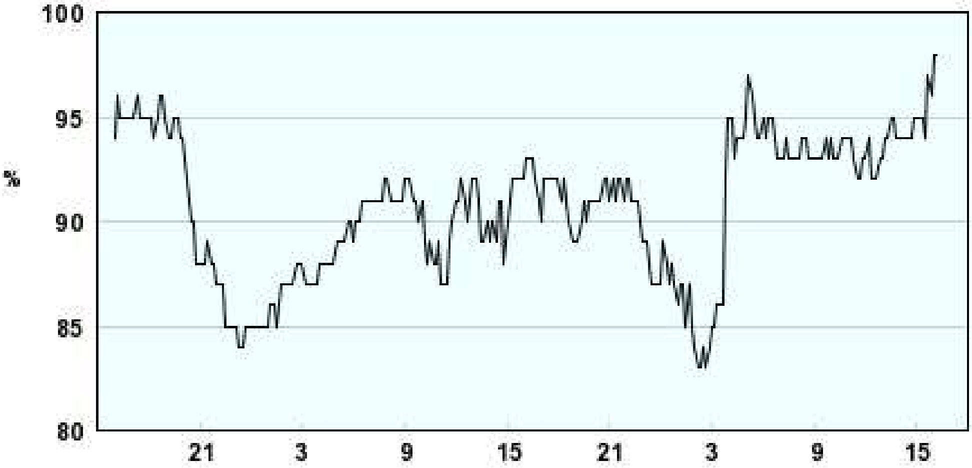


Diagram 2. Humidity from November 30th, afternoon to December 2nd, afternoon

Diagram 3. Wind speed from November 30th, afternoon to December 2nd, afternoon

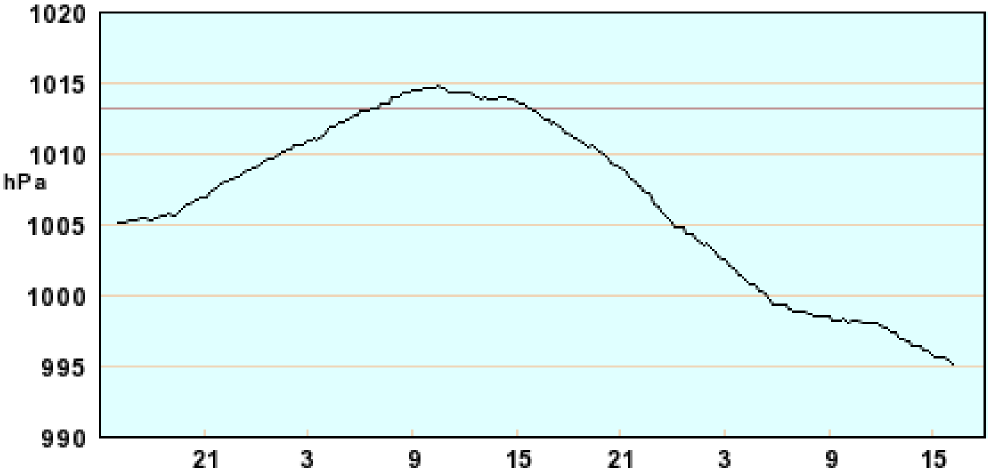


Diagram 4. Atmospheric pressure from November 30th, afternoon to December 2nd, afternoon

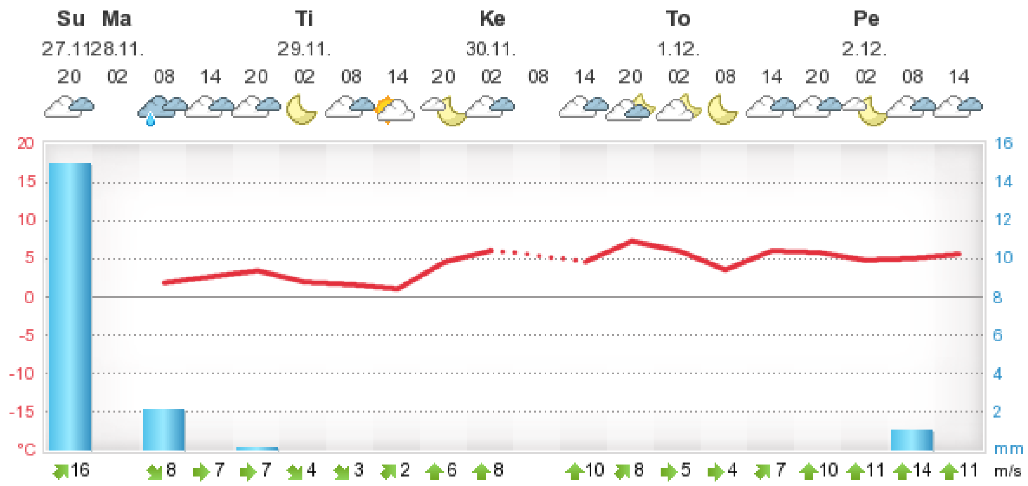


Diagram 5. Cloudiness, temperature, wind and precipitation from November 27th, evening to December 2nd, afternoon

3.1.3 Preparation of the blades

The two areas to be coated on the blades measured 3.5 square metres each. The area on blade 1 was situated at the tip of the blade, beginning from the tip up to a height of 5 metres, expanding to a width of 400 mm on the pressure side and 300 mm on the suction side from the leading edge. Measurements of the test area on blade 2 were exactly the same as on blade 1, only the location of the area was from 5 metres up to 10 metres measured from the tip of the blade.

The blades were extensively polluted with gear oil leaking from the nacelle and dirt. The gear oil leakage was explained to be caused by gaskets not designed for low viscosity oils suitable for low temperature application.

Preparation of the coating area on blade 1 consisted of thoroughly wiping with acetone drenched cloths, abrasion with an excenter sander using 120-grit sanding paper and then wiping all dust off with xylene wipes. After that, the area was allowed to dry completely before coating.

Blade 2 was prepared the same way, only with the difference that abrasion was performed by hand using heavy duty scouring pads. Preparation methods of the blades differed from each other to eventually get an impression about how carefully the substrate has to be prepared to achieve good adhesion.

Picture 1. Newly coated area clearly visible. Note heavy blade pollution.

3.1.4 Coating application

The application of the coating in the test area on blade 1 was performed in one coat using a paint roller and a brush to flatten out roller marks in a horizontal stroke. Producing a good finish proved to be quite challenging using this technique in the prevailing weather conditions of that day. Obviously as a result of low blade surface temperature, viscosity of the coating increased significantly on contact with the surface. This made even distribution difficult and caused runs in the coating.

In an attempt to increase surface quality, the coating on blade 2 was applied in two thin paint roller coats. In the upper part of the test area, from 7 metres to 10 metres from the tip of the blade, a roller finish was left and in the lower part from 5 metres to 7 metres height, the surface was again flattened with a brush.

Applying two thin coats proved to work, as the coating covered well and smoothed out sufficiently.

In order to cure the coating faster and testing if warming the coated surface would have an effect on surface quality, an area of 0.08 square metres at the 5 metre mark of blade 2 was warmed up to 40 degrees Celsius by applying hot air. This resulted in a quick decrease in coating viscosity causing again runs in the surface.

In addition to the test areas on the blades, a grp-plate (420 mm x 250 mm) with gelcoat surface, comparable to the blade materials, was coated with NWE SALES Nordic Anti-Friction Silane. The plate was left to cure at the foot of the turbine and fetched 24 hours later. It was then placed outside on the author’s balcony and left there for one year until laboratory testing was commenced. For that year, the plate had been exposed to the elements to age it for laboratory testing and to observe any changes in surface appearance.

3.2 Inspection of the coated areas

3.2.1 Characteristics of winter season 2011/2012

During the winter following test coating of the blades of 1 MW wind turbine “Ilona”, the condition of the coating was inspected two times. First inspection was carried out on January 13th, 2012 and second on April 24th, 2012. Weather conditions were relatively moderate during inspections with temperatures hovering around -1 degrees Celsius and no precipitation on the morning of the first inspection and clearly above zero temperatures during second inspection.

Although the winter in Kotka had been approximately 1.5 degrees Celsius warmer on average than the winters between 1981 and 2010, February had been colder than average [12]. Kotka saw a continuous period of frost from January 21st to February 20th, and during this time temperatures sank below -20 degrees on 7 days. The coldest night was experienced on February 5th, when temperatures sank to -29 degrees Celsius. [13]

Despite regularly occurring low temperature periods in winter, Kotka only infrequently sees icing conditions due to its geographical location and topography. The winter of 2011/2012 was no exception, and the wind turbine had not been subject to severe ice accumulation. Answering to an inquiry about this topic, both Managing Director Vesa Pirtilä and Production Manager Sami Markkanen of Kotka Energy confirmed that the turbine had run without any problems throughout the winter. Therefore, the field-test did not give any answers about the anti-ice properties of the coating.

3.2.2 Mechanical and surface quality of the coated areas

Following observations about mechanical properties concerning adhesion, cohesion, cure and finish could be made: the coating had obviously cured sufficiently already before restarting the turbine the day following application, as the surface did not show any signs of impairment due to rotational forces. Also was the coating fully intact, with no signs of flaking, cracking or detachment from the substrate. Adhesion and cohesion respectively appeared to be of very good standard.

To confirm this, the surface was attacked at various points and around the edges with a metal scraper, but no detachment of the coating could be inflicted. During final inspection a multi-blade cutting tool was used to cut lattice patterns into the coating at different locations around the test areas. Only at one single lattice pattern on blade 2 two removed squares could be observed. The overall result was therefore satisfying also on the blade prepared only by hand using scouring pads.

The finish of the coating showed facile horizontal brush strokes and a slightly mottled surface, where the roller finish had been left. From the brush stroke finish, the thin layer of grime and dust that had accumulated since coating could be wiped away with a dry cloth easily. Concluding from this phenomenon, self-cleaning properties of the coating could be diagnosed. This was in clear contrast to the original gelcoat surface, which would not wipe clean without the use of detergents. Only the unevenness of those parts of the test areas that had a mottled surface from roller distribution made them more difficult to clean.

Furthermore, the finish of the coating could be described as semi-gloss. The hydrophobic properties were obvious, as rainwater running down the blades transformed into beads upon coming up against the newly coated surface, whereas it was forming a film on the original uncoated surface.

Picture 2.Test area around leading edge. Semi-gloss surface.

Picture 3. Good surface cleanability.

4 LABORATORY COMPARATIVE TESTING REPORTS

To improve understanding about the coating properties, a number of tests were conducted under laboratory conditions, following international testing standards as closely as possible. These tests were chosen based on their feasibility in a laboratory not adequately equipped for testing of coating systems and on their potential to add useful information to the still incomplete material properties database.

The testing followed the procedure described in the standards exactly except where deviation from standard procedure is mentioned separately. All testing and assessment was done by the author of this thesis.

4.1 Determination of film hardness by pencil test

4.1.1 Purpose

The first laboratory test performed was the determination of film hardness by pencil test, following International Standard ISO 15184:2012. The standard describes a method to determine the hardness of a coating by trying to inflict damage to the coated surface pushing pencils of growing hardness grades across the surface. After the film hardness of NWE SALES Nordic Anti-Friction Silane had been defined, the same test was for comparison executed also on a standard gelcoat surface which can typically be found on many wind turbine blades.

4.1.2 Test panel preparation

The test panel was laminated from glass fibres and polyester resin on a glass table treated with mold release agents. These materials were chosen as substrate, because they were thought to represent a real coating situation on wind turbine blades best. Using a treated glass table ensured obtaining a smooth surface on the test panel and an easy release. The measurements of the finished test panel were 1600 mm x 900 mm.

On September 25th,2012, two layers of gelcoat (Crystic 65Pa, a general purpose osmosis resistant isophthalic gelcoat) were applied with a roller to the table surface. Wet layer thickness was 560 microns and an amount of 990 grams of gelcoat had been used, leaving cup residues out of count. After 24 hours of curing, five layers of 650 g/m² CSM (Chopped strand mat) glass fibre mats followed in hand lay up, impregnated by 6.2 kg of polyester resin and MEKP -catalyst in total.

The test panel reached a total of 11.9 kg in weight and 5.5 mm in thickness.

Picture 4. Glass table ready for coating.

Picture 5. Gelcoat painted.

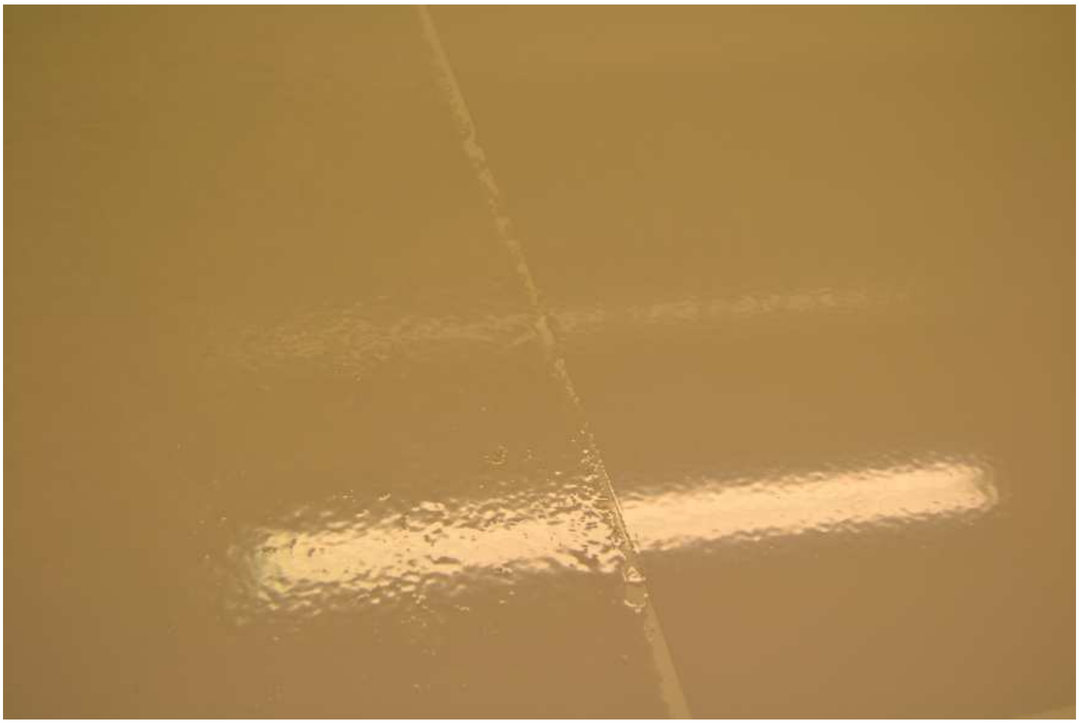
Picture 6. Test panel laminated.

The first attempt of applying NWE SALES Nordic Anti-Friction Silane to the test panel was carried out on November 13th, 2012. The surface of the gelcoat was degreased wiping it thoroughly with acetone and then abraded with an excenter sander using 120-grit sanding paper. The area to be coated measured about 700 mm x 500 mm.

After affirming the right mixing ratio of paint and hardener on the telephone with Kimmo Kaila of NWE Sales, paint and hardener were mixed in a mass ratio of 100:28 and distribution forthwith begun. Temperature during painting was 21° Celsius. Immediately after starting to spread the coating with a roller, it became clear that viscosity of the paint at this temperature was too low to get satisfying results from roller distribution. The paint did not cover, and furthermore made fluff from the roller the surface very uneven.

Inspection of the cured surface two days later confirmed the concerns, and the test area was discarded.

After preparing another area of the same size as the previous one on the panel (wiping and abrading), the area was taped and the rest of the panel covered with plastic foil for spray paint application on November 19th, 2012.



Picture 7. Test panel surface. Note the difference between the discarded area (left) and the area good for testing (right).

Paint was then applied with conventional spraying equipment in four layers wet to wet, until a wet film thickness of 120 microns was achieved. Wet film thickness was therefore within the guideline thickness of 100 - 125 microns determined by the manufacturer. An amount of 120 g paint and 34 g hardener was used, of which about 10 g stayed in the cup as residue.

Surface quality proved to be very satisfying and the panel was left to cure thoroughly until November 27th, 2012. Temperatures and relative humidity during the curing process can be observed from the diagram below.

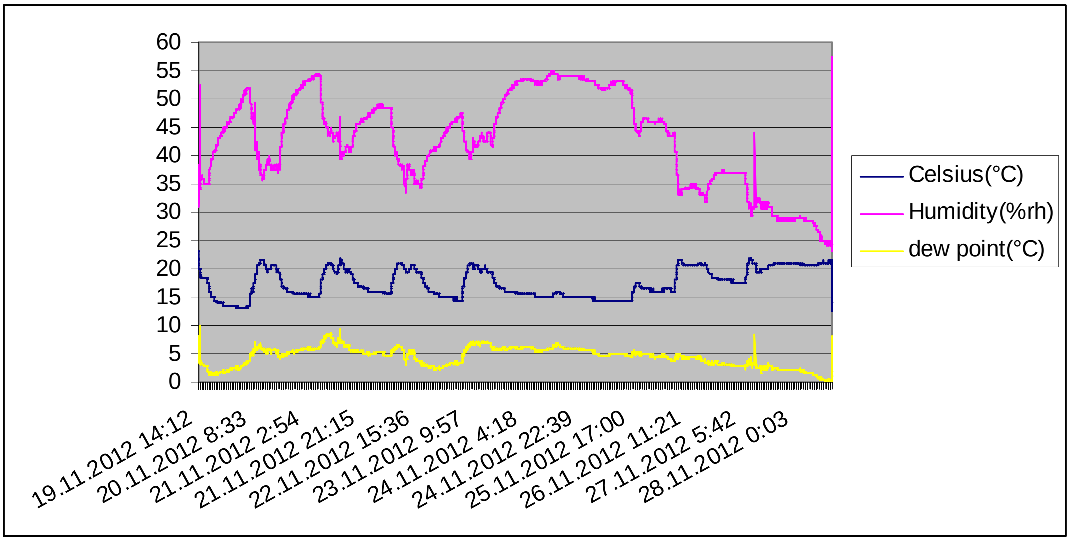


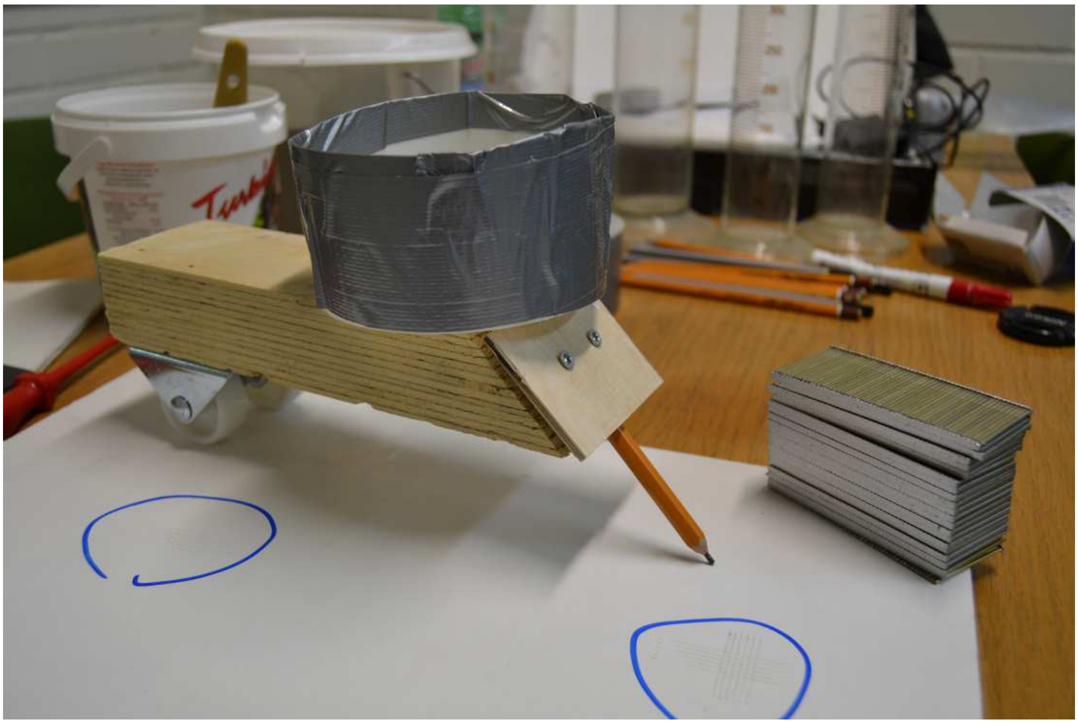
Diagram 6.Temperatures, relative humidity and dew point during curing process

In addition to the test panel prepared under laboratory conditions, testing was also performed on the field-test plate coated simultaneously with the test areas on the rotor blades of wind turbine Ilona on December 1st, 2011. Also this plate had been laminated from glass fibres and polyester resin with a layer of gelcoat on the surface. Plate measurements were 420 mm x 250 mm x 10 mm. Before coating the plate using a roller on December 1st, 2011, one half of the surface of the plate was abraded using an excenter sander with 120-grit sanding paper, while the other half was abraded using only heavy duty scouring pads. Wet film thickness could not be determined at that time, but exceeded manufacturer recommendations due to high paint viscosity at the prevailing temperature.

The plate was left to age on the author’s balcony for almost a year, exposed to the elements, until on November 28th, 2012, it was brought to the premises testing was performed in.

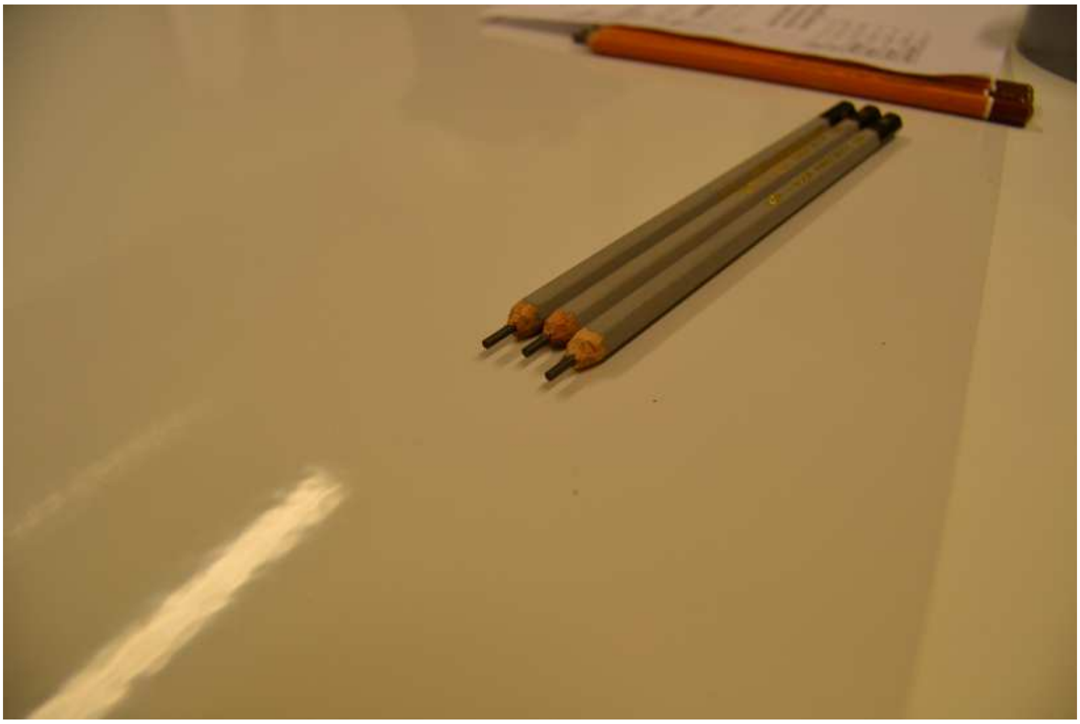
4.1.3 Apparatus and materials

Performing the determination of film hardness by pencil test requires suitable equipment:



Picture 8. Ttest instrument and weights. Weights are put into the cup on top of the instrument.

1. A test instrument that is designed so that it holds the pencil in an angle of (45 ± 1)° towards the paint surface (picture 8). The weight of the instrument must induce a force of (7,5 ± 0,1) N from the tip of the pencil to the paint surface. 7.5 N correspond to approximately 765 g of weight.
2. A set of wooden drawing pencils. Complying with the International Standard, a set of KOH-I-NOOR, grade 2B (soft) to 9H (hard), by Hardtmuth AG was used for this test (picture 9).
3. A special mechanical sharpener which will remove the wood only. In this case, a cutter was used to carefully remove the wood from the pencil points.



Picture 9. Pencils shaped according to International Standard.

4. Abrasive paper grit No. 400.
5. A soft cloth to clean the test area after the test.

4.1.4 Testing of film hardness

The testing of the laboratory panel, coated using a spray gun, was carried out on November 27th, 2012 at a temperature of 21° Celsius and a relative humidity of 38 %, which represented a deviation of 7 % from test conditions proposed by the standard ((50 ± 5) % relative humidity). Testing of the field-test panel was executed on December 12th, 2012 at a temperature of 21° Celsius and a relative humidity of 36 % (deviation 9 %).

After 5 mm to 6mm of wood had been removed from the point of each pencil with a cutter, the tip of the lead was flattened by moving the pencil back and forth over abrasive paper, maintaining an angle of 90˚ (see picture).

The pencils were then, beginning with the softest grade (in this case 2B), inserted into the test instrument and pushed across the coating at a uniform speed. The inspection of the panel for possible markings was done after 30 s using normal vision.

The test was executed in duplicate on both laboratory and field-test panel, as well as on the blank gelcoat surface of the laboratory test panel.

4.1.5 Test results

The test carried out in duplicate gave following results:

Table 1. Results of determination of film hardness by pencil test

Pencil hardness NWE SALES Nordic Anti-Friction Silane (laboratory panel)	Pencil hardness NWE SALES Nordic Anti-Friction Silane (field-test panel)	Pencil hardness Crystic 65Pa isophtalic gelcoat
B	**6H**	**HB**

In all cases, a cohesive fracture of the surface could be observed, in other words a visible scratch or rupture. However, the scratches were very fine, visible only under very close examination in good lighting conditions.

The NWE SALES AFR coating painted 8 days before pencil hardness testing proved to be one grade softer than the Crystic 65Pa gelcoat which is in the middle of pencil hardness range 9B - 9H. The coating that had cured and aged for one year on the other hand showed a film hardness 6 grades above the gelcoat's hardness. This could be an indication that it takes longer than 8 days for the coating to reach its final hardness under conditions described above. Differences in composition of the batches of coating (1 year time difference) could also be partly responsible for the variation as well as an increased amount of hardener used. However, the amount of hardener that had been used when mixing the paint for field-testing (100:25, mixed by Kimmo Kaila) was in fact lower than the amount used for laboratory testing (100:28), as Kimmo Kaila of NWE SALES stated answering to an inquiry.

It is worth noting that, when comparing the gained results to other coating pencil hardnesses, the earlier versions of International Standard ISO 15184 allowed the test to be performed by hand without the use of a test instrument. As the amount of pressure induced to the surface through the edge of the pencil lead and the angle of attack are considered crucial, the comparison to test results from before 2012 is not advised.

4.2 Cross-cut test

4.2.1 Purpose

Generally, cross-cut testing refers to the cutting of lattice patterns into a coating, penetrating through to the substrate, with either a single- or multi-blade cutting tool in order to assess the resistance of the paint to separation from the substrate or between layers. The testing of NWE SALES Nordic Anti-Friction Silane followed procedure described in European Standard EN ISO 2409:2007 and took place on November 29th, 2012.

4.2.2 Test panel preparation

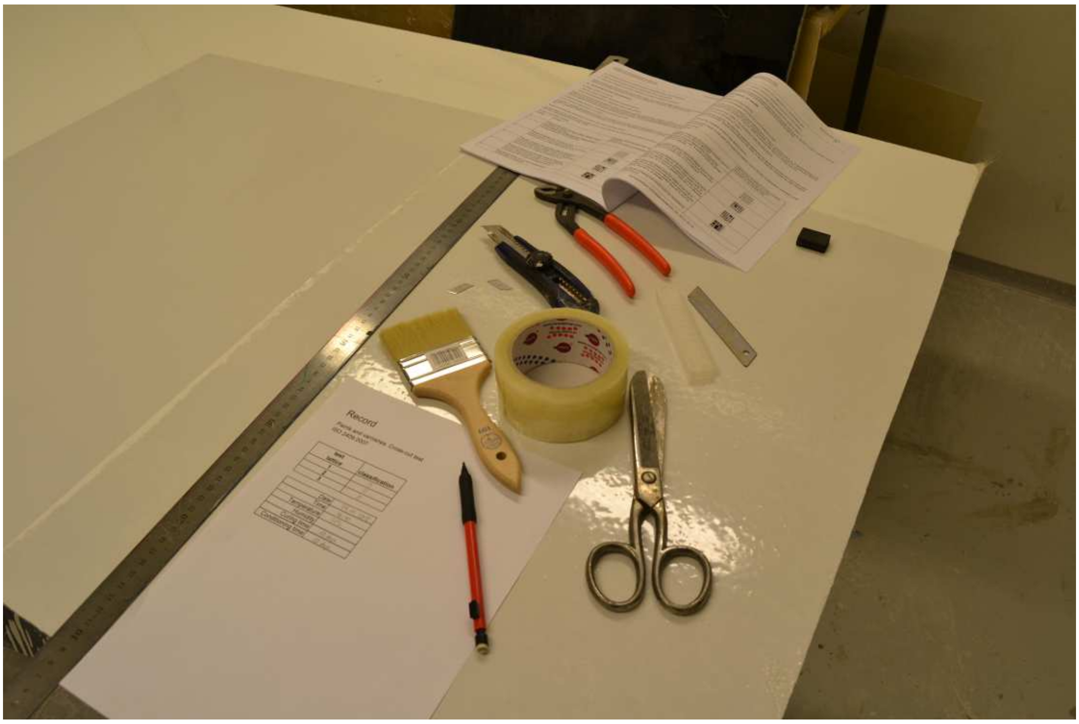
The same test panels were used for both determination of film hardness by pencil test and cross-cut testing. Obviously, the tests were only carried out in different areas of the test panels. For details on test panel preparation refer to chapter 4.1.2, *Test panel preparation*.

4.2.3 Apparatus and materials

Following apparatus was utilized for the execution of the cross-cut test:

1. A single-blade cutting tool. In this case a common cutter.
2. A metal ruler for marking distances between cuts and serving as guiding edge.
3. A soft brush.
4. Transparent pressure-sensitive adhesive tape, 50 mm wide. ISO 2409:2007 specifies tape with an adhesive strength between 6 N per 25 mm width and 10 N per 25 mm width. An Eurocel Sicad carton sealing tape was chosen for this test, however no information could be found which tape it was exactly. The adhesive strength of most transparent

Eurocel carton sealing tapes is between 5N and 10 N per 25 mm width [14].



Picture 10. Apparatus and materials used for cross-cut testing.

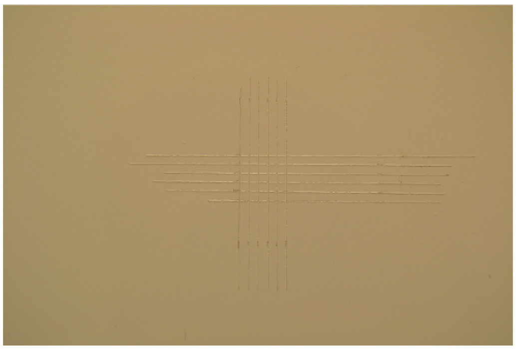
4.2.4 Cross-cut testing

The test was carried out on November 29th, 2012 at a temperature of 21° Celsius and a relative humidity of 35 %, which represented a deviation of 10 % from test conditions proposed by the standard ((50 ± 5) % relative humidity).

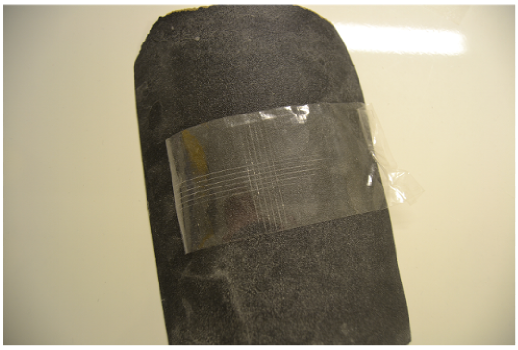
Using the metal ruler and a propelling pencil, exact marks on the test panel were made to create auxiliary lines for the lattice patterns. Five lattice patterns (picture 11) in total were then cut at different locations on the two panels, three on the panel coated under laboratory conditions and two on the panel painted one year earlier in connection with the field-test. For cutting, the metal ruler was used as guiding edge. Patterns consisted of 6 cuts in each direction with a spacing of 2 mm. Of the patterns cut into the field-test panel, one was on the side abraded with an excenter sander and the other on the side abraded using scouring pads.

To ensure blade sharpness at all times, a piece of the blade was snapped off after cutting each lattice pattern.

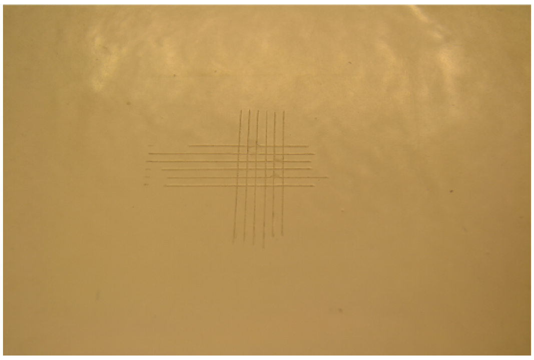
After cleaning the patterns by brushing lightly, a strip of adhesive tape about 75 mm long was placed on each pattern, rubbed firmly to ensure good contact to the surface and then pulled off (picture 12). Immediately after removing the tape, lattice pattern and tape were examined using normal vision.



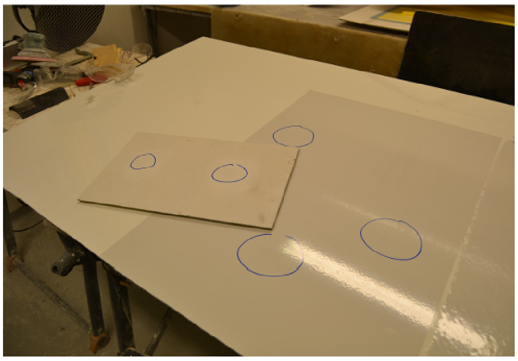
Picture 11. Typical lattice pattern on laboratory panel.



Picture 12. Transparent tape after being pulled off the pattern



Picture 13. Lightly affected field-test panel.



Picture 14. Location of test areas on panels.

4.2.5 Test results

Standard ISO 2409:2007 provides a six-step classification for coatings cross-cut tested, where 0 represents outcomes of the best standard and 5 affection of over 65 % of the cross-cut area by flaking or detachment of squares. After careful examination, the following classifications for the 5 lattice patterns could be made by comparison to the illustrations in the standard:

Table 2. Results of cross-cut test

Test lattice	Classification	Panel
1	0	laboratory panel
2	0	laboratory panel
3	0	laboratory panel
4	1	field-test panel, scouring pad abrasion
5	0	field-test panel, excenter sander abrasion

Standard description for classification 0: “The edges of the cuts are completely smooth; none of the squares of the lattice is detached.”

Standard description for classification 1: “Detachment of small flakes of the coating at the intersections of the cuts. A cross-cut area not greater than 5 % is affected.”

The adhesion of NWE SALES Nordic Anti-Friction Silane to the substrate therefore fulfils the requirements of the standard, regardless of which of the methods of abrading the substrate described in this study had been applied. The flaking and detachment of parts of the coating in the scouring pad abrasion -area of the field-test panel can be affiliated to excessive film thickness and should not be taken into account when assessing adhesion.

4.3 Modified Bandow-Wolff test

4.3.1 Purpose

The Modified Bandow-Wolff test (ISO 9117-5:2012) is part 5 of a series of six standards dealing with drying tests for paints and varnishes. It is applied for assessing drying speeds and includes in itself also European standard EN ISO 9117-3 (Surface-drying test using ballotini).

The test comprises two different methods. For surface dryness, fine glass spheres (ballotini) poured onto the drying surface indicate surface dryness at the time they can be brushed away. Subsequent drying stages are assessed using paper discs and weights. A paper disc that drops off easily after having been pushed to the surface for a certain time using a certain weight indicates the affiliated drying stage.

The objective was to test NWE SALES Nordic Anti-Friction Silane for drying speed in different surrounding temperatures at a constant relative humidity. These plans were abandoned during the first test round due to the immense time effort that would have been required. Instead, the surface drying times of the coating at constant 20° Celsius and relative humidity of 60 %, 75 % and 90 % were determined. This involved only ISO 9117-3 (Surface-drying test using ballotini).

4.3.2 Test panel preparation

Substrate panels were cut out of the plate laminated earlier for testing purposes, which consisted of a glass fibre and polyester resin laminate with a Crystic 65Pa -gelcoat surface. For details on test panel preparation, refer to chapter 4.1.2, *Test panel preparation*.

Panels were cut using an angle grinder equipped with a ceramics blade and measured about 150 mm x 95 mm x 5.5 mm.

4.3.3 Apparatus and materials

The modified Bandow-Wolff test requires materials for both surface dryness and drying stage testing. For this study following objects were utilized:

1. Small transparent glass spheres (ballotini). Deviating from the standard, Trelleborg Fillite SG silicate spheres were used here. Particle size was limited to 50 - 280 microns by sieving instead of 125 - 250 microns, as standard proposes.
2. A soft brush.
3. Paper discs with a diameter of 26 mm cut out of normal typing paper.
4. Rubber discs , diameter 22 mm and thickness 5 mm. Medium hardness.

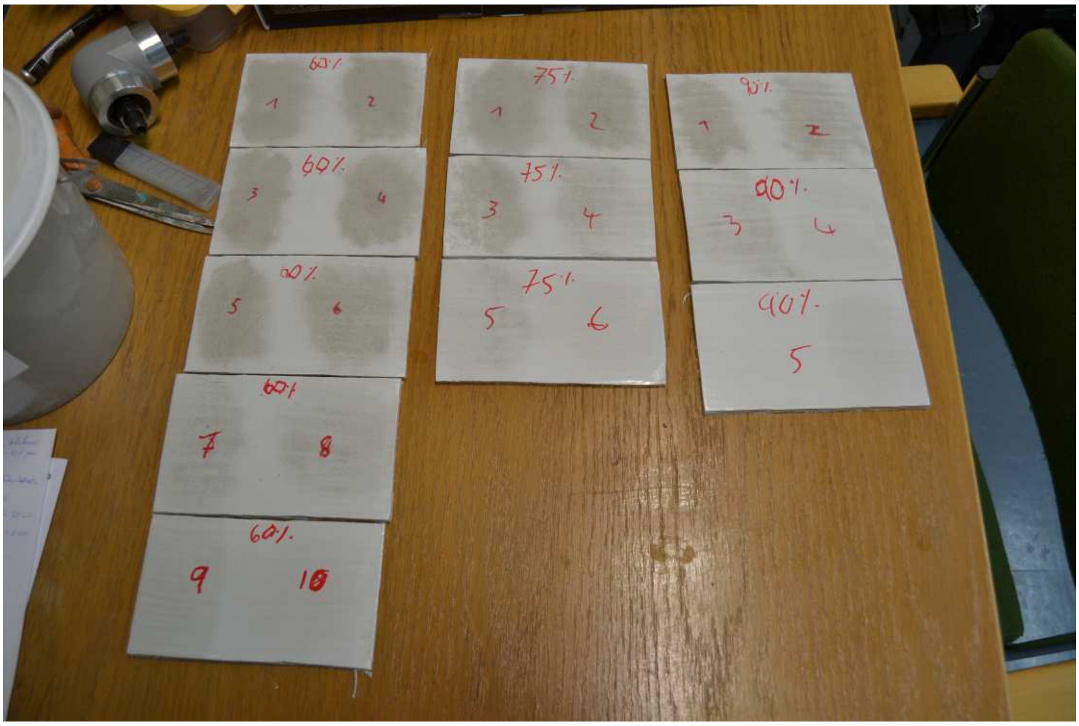
5. Weights of 20 g, 200 g, 2 kg and 20 kg.
6. A stopwatch.
7. A glass tube.
8. An Arctest ARC-1500 environmental test chamber.

Picture 15. Drying speeds test setup

4.3.4 Drying speed testing

Drying speed testing was commenced on December 7th, 2012. As the initial aim of the test was to determine the coating drying speed at the temperatures of 30° Celsius, 20° Celsius and 10° Celsius and a relative humidity of 60 %, the Arctest environmental test chamber was set to 30° Celsius and 60 % humidity for the first round of tests. 32 g of coating was mixed with 9 g of hardener (100:28) and applied to six test panels with a brush, obtaining a wet film thickness of 102 - 127 microns.

Panels were then placed in the test chamber and half-hourly checked for curing process, first only testing surface stickiness using a finger and later applying the ballotini -test method. For this method, one test panel was taken out of the chamber and 0.5 g of ballotini poured from a glass tube onto the surface. Pouring from a glass tube limited the size of the area the ballotini spreaded onto and thus enabled further testing on the same panel. After 10 seconds, it was attempted to brush away the ballotini. Surface dryness was achieved when all ballotini could be brushed away without causing any damage to the coating surface (picture 16). Tests were performed in triplicate. In the case of the first test round, surface dryness was reached after 6 hours and 30 minutes. The test round was continued for the determination of drying times of drying stages 2 - 7.



Picture 16. Ballotini test panels displaying different stages before surface dryness

For the determination of drying stages 2 - 7, panels were again taken out of the testing chamber at certain time intervals. A paper disc, a rubber disc and a weight (beginning with 20 g and proceeding to 20 kg) were then placed on the surface. After 60 seconds, weight and rubber were removed and the plate was dropped vertically from 30 mm height. If the paper disc dropped off, the affiliated drying stage had been reached.

However, when after 7 hours and 45 minutes drying stage 2 was still not reached, the first test round was stopped. 10 hours later, the panels were again tested for drying stage 2. For those 10 hours, they had been in surrounding temperatures between 15° Celsius and 20° Celsius and a relative humidity between 35 % an 40 %, but drying stage 2 had still not been reached.

The original plans were therefore abandoned due to the immense time effort that would have been necessary to carry out all drying tests, and a decision was made to test NWE SALES Nordic Anti-Friction Silane only for surface drying times at different percentages of relative humidity and a constant temperature of 20° Celsius.

The testing of surface drying times at a relative humidity of 60 %, 75 % and 90 %, applying the Surface-drying test using ballotini described above, was carried out on December 8th and 9th, 2012. As the results from the first test carried out at 60 % relative humidity appeared to be false, probably due to a mistake done while mixing the coating components, the test was repeated on December 10th, 2012. This time the results were consistent.

4.3.5 Test results

The diagram below shows the surface drying times of NWE SALES Nordic Anti-Friction Silane at a constant temperature of 20° Celsius and relative humidity of 60 %, 75 % and 90 %.

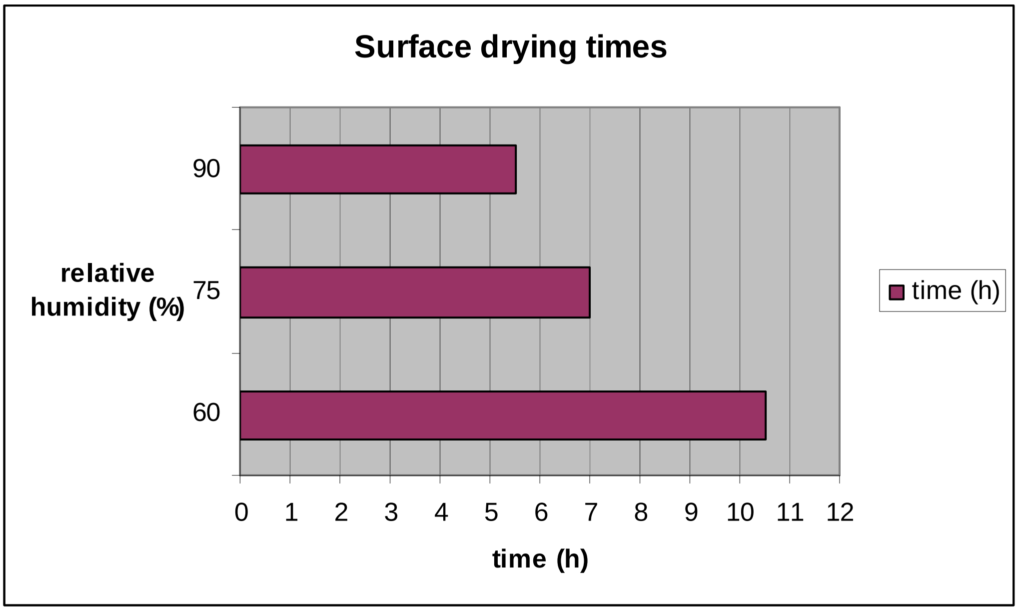


Diagram 7. Surface drying times

Progress of the drying tests had been consistent and the results were plausible.

5 CONCLUSION

NWE SALES Nordic Anti-Friction Silane showed a very good performance in terms of material properties tested in this study. Deviations from test procedures described in the standards remained modest, thus the results can be taken as valid.

The field-test revealed very good adhesion of the coating in combination with both ways of substrate preparation applied, and also obvious dirt repelling properties. Furthermore the coating exhibited the ability to cure even in temperatures of 4 - 6° Celsius. Only the paint viscosity proved problematic under the aforementioned conditions and surface quality resulting from roller distribution, as laboratory testing confirmed. Adjusting viscosity to different temperature ranges in combination with spray gun application will eliminate these problems.

As winter season 2011/2012 did not give the possibility to observe anti-ice properties of NWE SALES Nordic Anti-Friction Silane on-site and no sufficient laboratory equipment to perform suitable tests was available, no statement about anti-ice properties can be made. Future tests performed by other parties will provide information concerning this topic.

Film hardness determination yielded a much lower pencil hardness grade for the laboratory-made panel than for the field-test panel. Obviously, as confirmed by the drying speed tests, drying under low humidity laboratory conditions lengthens the curing process of NWE SALES Nordic Anti-Friction Silane to that extent, that 8 days drying time had not been sufficient to fully cure the coating. Therefore pencil hardness grade 6H, obtained from testing the field-test panel, should be considered as the coating’s pencil hardness. Grade 6H can be treated as equivalent to a very hard grade. This also supports previous test results concerning the coating’s ability to resist abrasion, where it had performed very well.

No problems were encountered during the cross-cut testing and the results were of the best standard. In other words, the adhesion and cohesion of the coating were outstanding, also when the substrate had not been thoroughly abraded before coating.

Surface drying speed tests provided predictable results in terms of the effect of humidity on curing times and furthermore specified concrete drying times of the coating for different percentages of humidity at a constant temperature. These gave an impression of the curing behaviour of the coating and can from now on be taken as a guideline when applying the coating under similar conditions.

Synoptically speaking, this study has produced a number of positive results that can be added to the already existing material database and encourages further tests to find out about the rest of the material properties, in particular anti-ice properties.

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