OULUN AMMATTIKORKEAKOULU

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SCREW CORROSION AFTER 720 HOUR SALT SPRAY TEST

Screw Corrosion after 720 Hour Salt Spray Test

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Tämän työn tarkoituksena on tutkia tukiaseman ruuvien korroosionkestoa 720 h suolasumutestin jälkeen. Työssä testattiin ruuveja eri pinnoitteilla korroosioympäristössä. Osa testattavista ruuveista on jo käytössä Nokia Networksilla ja osa on kokonaan uusia. Tarkoitus on verrata uusien ratkaisujen suorituskykyä nykyisiin.

Korroosiolla yleisesti on sekä taloudellisia että laadullisia vaikutuksia lopputuotteeseen. Oikeilla ruuvivalinnoilla oikeaan ympäristöön voidaan säästää kustannuksissa. Näin voidaan myös minimoida laatuongelmat, joka mahdollistaa tuotteen kilpailukyvyn monilla eri tasoilla. Testitulokset kattavat sekä visuaalisen tarkastuksen että teknisen testauksen, jolla varmistetaan parhaan vaihtoehdon valinta.

Systemaattinen lähestymistapa testauksessa on tärkeää, jotta mahdolliset ongelmat voidaan tunnistaa ja riskit minimoida. Tämä työn tarkoituksena on myös osaltaan mahdollistaa oikeiden ruuvien valinta oikeaan kohteeseen ja ympäristöön.

Asiasanat: korroosio, ruuvi, testaus

ABSTRACT

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The objective of the thesis is to study corrosion of the screws in a base station after 720 h salt spray test. Screws with different coatings were tested and the performance is compared to the current solutions.

The corrosion in general has both economical and quality influence on the final product. By selecting proper screws to the right environment, lots of costs are saved. Additionally possible quality problems are minimized, which enhances the competitiveness of the product in many levels.

The testing of the screws cover both mechanical and visual tests in order to secure the selection of the best possible solution. The possible failure analysis of each solution takes place as well. It is important to have a systematic approach to recognize and mitigate corrosion problems.

The target of the thesis is also to make sure that the test results support the screw selection. It is also important that the test results correlate with the requirements.

Keywords: corrosion, screw, testing

SISÄLLYS

1 PREFACE

This thesis has been done for Nokia Networks, which is a manufacturer for telecom equipment. In telecom industry, products are in a harsh environment in many cases, for example in the top of the tower exposed to all kind of environmental conditions. Screws are an important part of the product and are also the visible part of the product to the end customer.

By controlling and testing of our products in a systematic way the quality can be insured in any circumstances. In the case of screws, the product has been exposed to the similar testing in use to any other product in the telecom area. It means the functionality of the product has to be on the same level after testing.

In this thesis corrosion is the focus area. The test results included in this work give a clear guide-line, whether current screws in use are the right choices and can those selections be challenged by any other new product in tests.

2 INTRODUCTION

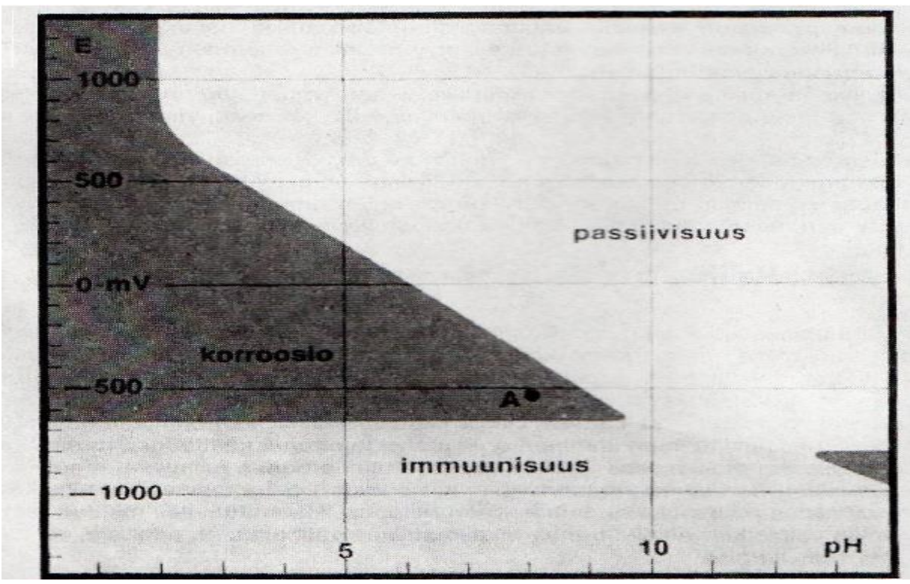
As a word, corrosion describes all chemical and galvanic destruction due to environment. Technical development has increased the significance of the corrosion. It is not only the increased usage of metals in different industries, but also larger mechanical and chemical requirements for metals i.e. high temperature, and chemical stress.

Increasing awareness of limited raw material resources has affected to the research of raw materials. It is not only exhaustion of ore globally, but also the manufacturing, which requires lot of carbon, oil and electricity.

The classical chemistry finds metal as a homogeneous element surface, which is only related to the chemistry in the environment. On the contrary, metal researchers are only concentrating on the structure of the metals and mechanical characteristics. Therefore, corrosion is a very good example of cross-disciplinary.

It is important to understand that different metals have different facilities for corrosion. The noble metals in the positive end of the voltage series, like gold and platinum, are non-corroded in many corrosion environments. The base metals in the negative end of the voltage series, like potassium, calcium and magnesium, are very responsive. In the table 1 situation in normal service water is shown. In the corrosion area Fe is corroded. In the passive area it protects from the oxidation layer. In the immune area, Fe is permanent in its metal form and is not corroded. (Kunnossapitoyhdistys ry 2004.)

TABLE 1. *Pourboix – diagram for Fe*

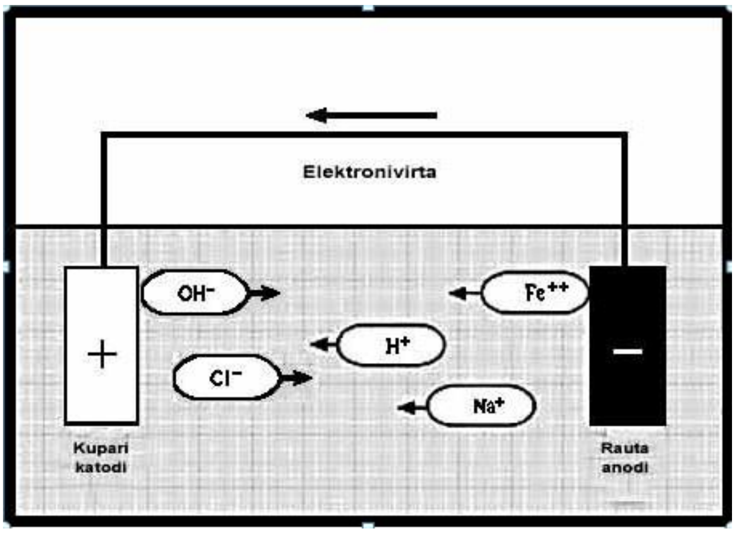


2.1 Galvanic Corrosion

Galvanic corrosion is an electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact. This is based on the development of the corrosion pair between two metal surfaces with different potential. The material with higher potential becomes a cathode and the material with lower potential becomes an anode. In other words the material with the higher potential is noble metal and the material with the lower potential is classified as base metal.

The origin of the corrosion pair requires not only creation of anode and cathode, but also electrical connection between the metals and electrolyte, which transfers the electricity between two metals. This creates a closed circuit, which works as long as the mentioned circumstances exist and there are no any polarization phenomena, which resist the corrosion. In the case of anode, metals dissolve as positive ions to the solution. The released electrons transfer from metal to the cathode through the conductor, where ion or dissolved oxygen reacts. The anode reaction in corrosion is always oxidation of the metal. (Kunnossapitoyhdistys ry 2004.)

TABLE 2. *Galvanic corrosion pair*



3 TESTED MATERIALS

In this chapter the materials in the tests are introduced.

3.1 Aluminum Plate

Die-Casted aluminum plates were ordered from mechanics supplier. Aluminum type is AlSi10Mg, which is normally used in telecom mechanics. By using the same materials it was possible to simulate real material conditions in testing. The aluminum plate used in the testing is a leftover from the die casting process. In the process molten metal is forced under high pressure in to mold cavity. In the mold cavity there are two hardened tools used, which are machined in the shape. Die – casting is quite simple way of manufacturing products, but on the other hand it has large capital costs due to mold investment.

FIGURE 1. *Die-casted unit with the leftover aluminum*

TABLE 3. *Technical data sheet of AlSi10Mg*

	As built	Heat treated T6 [5]
Ultimate tensile strength		
- in horizontal direction (XY)		
- in vertical direction (Z)	340 ± 40 MPa	315 ± 20 MPa
Yield strength (Rp 0.2 %)		
- in horizontal direction (XY)		
- in vertical direction (Z)	250 ±15 MPa	260 ±15 MPa
Elongation at break		
- in horizontal direction (XY)		
- in vertical direction (Z)	1.5 % ± 0.5 %	1.2 ± 0.5 %
Hardness [4]	120 ± 5 HBW	112 ± 5 HBW
Fatigue strength [6]		
- in vertical direction (Z)	97 ± 7 MPa	93 ± 3 MPa

3.2 Screws

The screws were ordered from supplier already used in Nokia. Some of the tested screws are already in use in Nokia i.e. SUS304 waxed, SUS304 Geomet and SUS316 waxed.

The following screws were tested:

1. SUS304 waxed M6x30
2. SUS304 Geomet M6x30
3. SUS316 waxed M6x30
4. SUS304 Deltatone M6x30
5. 10B21 Zn M6x30
6. SUS304 Zintek 200 M6x30

TABLE 4. *Mechanical properties of SUS304, SUS316 and 8.8*

Mechanical properties	AISI 304	AISI 316	8.8
Tensile Strenght, Ultimate	700 MPa	700 Mpa	800 Mpa
Tensile Strenght, Yield	450 MPa	450 Mpa	640 Mpa

3.3 Screws Coating

The plating of the screws was done by the material supplier. Geomet is already used in Nokia. The additional tested coatings were Delta Tone and Zintec.

In Geomet, the type 720 is in common use. This coating has many characteristics, which prevent the corrosion. It can be used without a topcoat, but can be painted if needed. It has a good multi-tightening behavior and it also maintains the performance at the higher temperatures up to 300 °C.

In Delta Tone, the type is 9000. This is inorganic micro layer zinc flake coating, which has a cathode protection by sacrificial corrosion of zinc. This coating is widely in use for screws, fasteners and springs.

In Zintec, the type is 200 + top coat L. This coating is based on the Atotech zinc flake coating. It is widely used in different industries from telecom to automotive. It has high temperature resistance and together with top coat it has resistance for the chemical stress as well. Top coat L is a chromium-free mineral coat, which increases the corrosion resistance and mechanical performance. In some cases screws are only waxed without coating. Waxing is done for lubrication in the assembly to avoid friction, which could damage the screw.

All tested coatings are widely known brands, which have a good track record in different kind of industries. There are lots of information and test results available about the coating. The suppliers of the screws have wide experience of the products and they have well established process in place in their production.

Zinc flake is one common factor in the coatings. It is non-electrically applied coating, which is a mixture of zinc and aluminum. Zinc flake is a generic term for coating technology and is marketed with different brand names among the suppliers. The specifications for the zinc flake coating are specified in the international standard ISO10683 and in the European standard DIN EN 13858 for the fasteners. Zinc flake coating creates a cathode protection for steel. The less noble zinc sacrifices itself in order to protect the metal underneath. In high volume products the suppliers use dip-spin coating. The basket of the products is dipped in to the container filled with the coating material. After the dip-spin residues are removed. (NOF Metal Coatings Group 2016.)

4 TESTING METHOD

In this chapter the used testing method is explained step by step.

4.1 Preliminary work

The surface of the premachined AlSi10Mg aluminum plates were machined in order to achieve even surface for drilling the thread. Machining was done by Serrmac milling machine.

FIGURE 2. *Machining of the aluminum plate*

4.2 Drilling the thread

The first phase was to drill the hole to the machined aluminum plate. Totally 20 holes were drilled to the each plate. The size of the drill was 5 mm. Next phase was to drill the thread to the aluminum plate by using 6 mm thread drill. The drilling was done by Serrmac drilling machine.

The aluminum plate was tightly fastened to the workbench in order to avoid any movement of the plate. It was vital to secure good and even quality of the drilled hole, as it has significant role in testing procedure.

4.3 Assembly of the screws

Each screw was assembled with the 6 Nm torque to the aluminum plate. Assembly was done with calibrated tool. This is the usual force used in real environment when base station products are assembled. The aluminum plate was again tightly fastened to the working bench to secure right angle and avoid any unevenness in drilling.

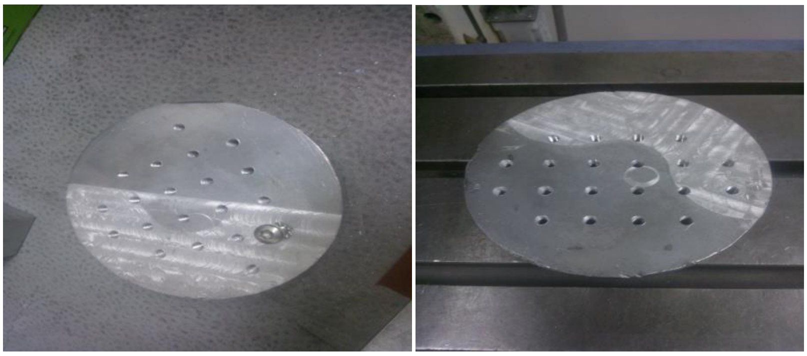


FIGURE 3. *Drilling the thread and assembly of the screws*

4.4 Salt spray test

The corrosion resistance in telecom equipment is tested in salt spray test. The salt spray test is standardized corrosion test method for corrosion resistance of materials and coatings. The appearance of the corrosion is measured after determined time of testing. The salt fog test is commonly used, because it is relatively cheap, fast and easily repeatable test to perform. In telecom equipment the used standard is Telcordia, General Requirement for Electronic Equipment Cabinet. In the test products are exposed for salt spray in the test chamber for 720 hours. The temperature is +35°C +1.1°C/ -1.7°C. Compound is 5% sodium chloride and 95% water. All mechanical features should continue to function satisfactorily after exposure to salt spray for 720 hours. After the test no visible signs of corrosion are accepted including stress corrosion, cracking or pitting. Test chamber used in this test is Vötsch VSC/KWT 450. This test method is used in Nokia also for other products and it is standardized way to ensure reliability of the products in the field. (Telcordia 2013.)

FIGURE 4. *Test chamber for salt spray test*

4.5 Opening test for screws

Torque test is typical test performed for the screws. By testing the products manufacturers and OEM: s are able to simulate real environmental conditions in the field. At the same time product quality and design can be verified. Deprag ME5400 measuring equipment is connected to PC. The screwdriver with the bar is rotated 360° to measure the torque value. At the same time system displays a graph and torque over time. It also shows the highest value of the torque needed.

FIGURE 5. *Deprag ME5400 measuring equipment*

5 TEST RESULTS

In this chapter the test results are introduced.

5.1 Visual inspection

In the visual inspection of the screws, no visible signs of red corrosion are accepted. This is valid for the head of the screw and the thread of the screw and aluminum. When using visual inspection the limitations of the testing method should be known. On the other hand visual inspection is a rapid way to recognize the corrosion and it is kind of first line of defense against the corrosion. The tested screws were in the testing chamber for 720 hours. After testing extra salt was washed out from the aluminum surface. The screws were inspected visually in the corrosion point of view in order to find visible corrosion on the screws. Thread of aluminum, thread of the screw and screw head were photographed by microscope camera.

In the screws already in use visual inspection is not showing any signs of rust. As figures 6 and 7 illustrate, thread in the screw and aluminum look fairly clear. Also the top of the screw doesn't show any signs of corrosion. Especially in SUS316, result is excellent in all 3 areas. There seems to be some residues in screw thread in figures 6 and 8, but that is most likely wax.

In the new tested screws, figure 11 shows no visible signs of corrosion are found in any of the 3 areas of inspection. In figure 9, there is a sign of red rust in the aluminum thread. Signs of friction can also be seen in the screw thread. In figure 10 some signs of beginning rust can be seen in all 3 areas and the performance seems to be very poor compared to the other tested screws.

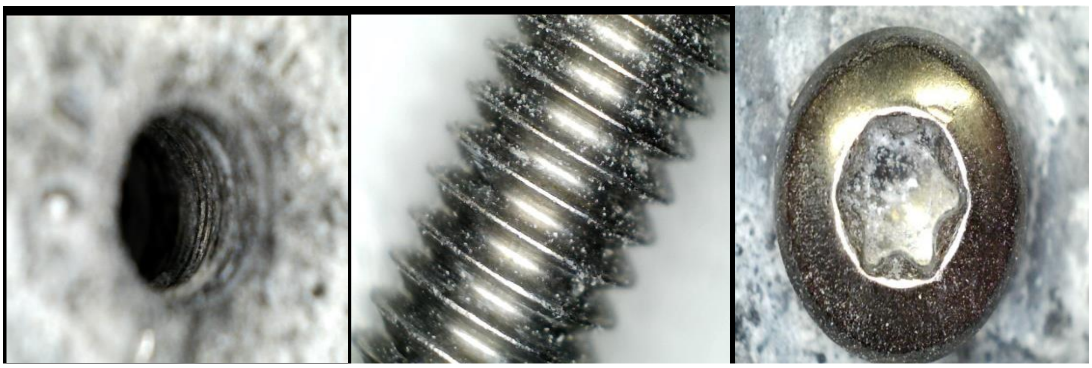


FIGURE 6. *SUS304 waxed, thread and head of the screw after salt fog test*

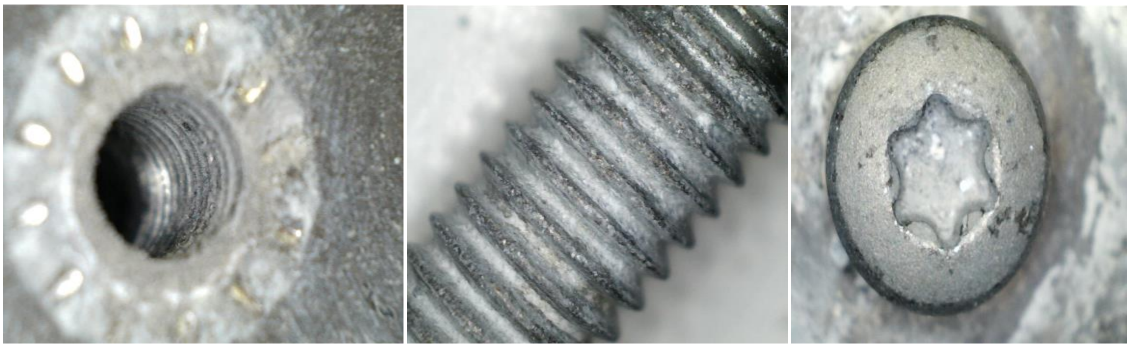


FIGURE 7. *SUS304 Geomet, thread and head of the screw after salt fog test*

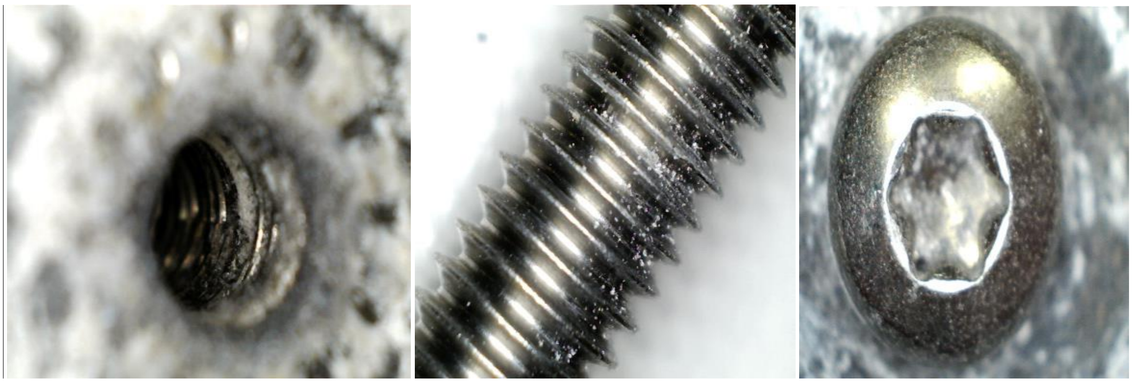


FIGURE 8. *SUS316 waxed, thread and head of the screw after salt fog test*

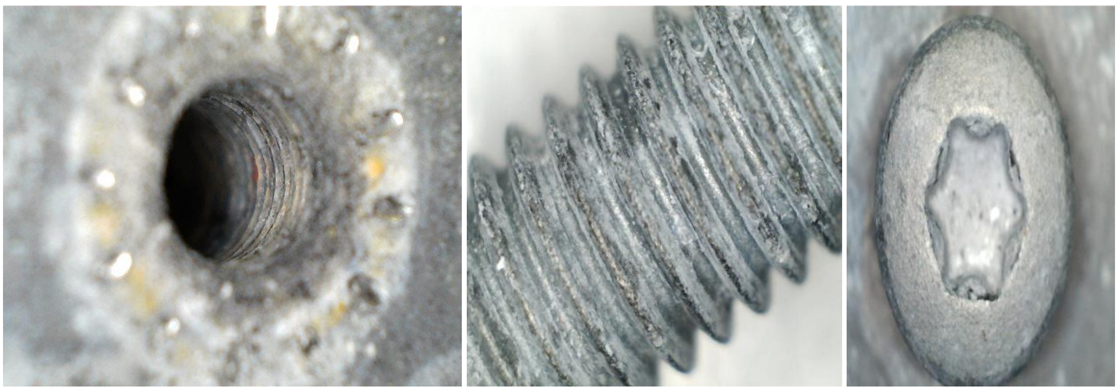


FIGURE 9. *SUS304 Delta Tone, thread and head of the screw after salt fog test*

FIGURE 10. *10B21 Zn, thread and head of the screw after salt fog test*

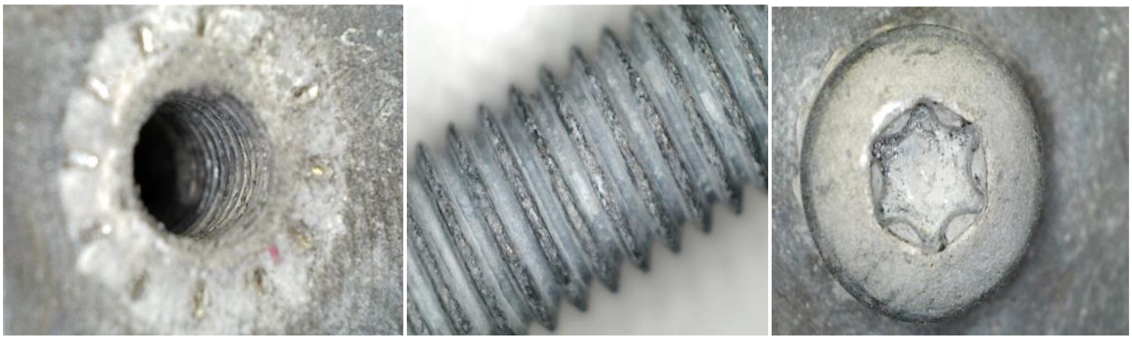


FIGURE 11. *SUS304 Zintek 200, thread and head of the screw after salt fog test*

5.2 Torque test

The screws were assembled with 6Nm force to the aluminum plate. The assembly was done with the calibrated tool. After salt spray test values of the torque were analyzed. In the torque test every assembled screw were opened and each screw had its own graph. Table 5 illustrates the torque for each screw in the test. Table 6 illustrates standard deviation with different screw types. Figures 12-17 are illustrating the highest value of torque for each screw type.

In the screws already in use a trend can be seen in the graphs. In figures of 12, 13 and 14 the graphs do not have significant deviations. Tested screw reaches the maximum torque in the very early phase of rotation. After that screw opens easily and no friction exists.

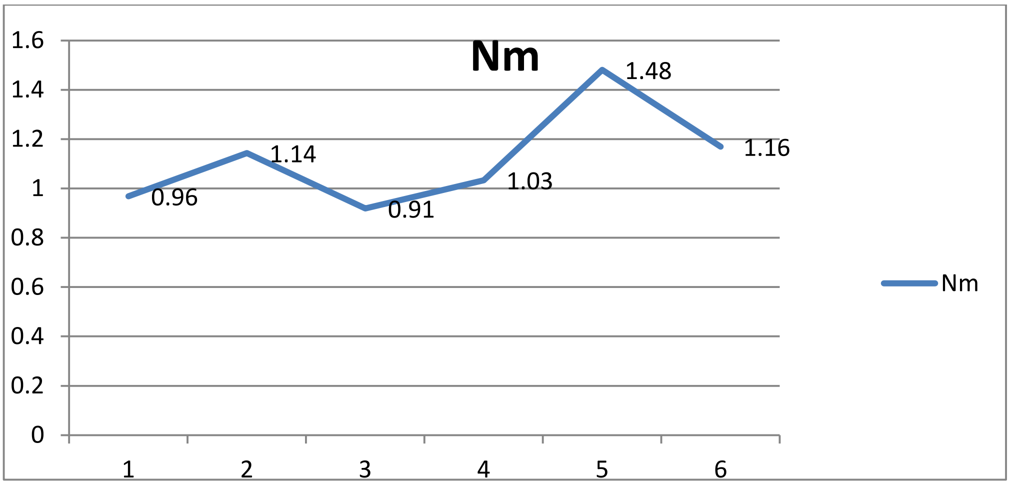
In the new screw types in figures 15 and 17, graphs also follow each other in outline. In figure 17 there is slightly more friction, which can be seen in higher values during the rotation.

On the contrary figure 16 shows significantly higher value in opening the screw and also friction during the whole test is visible. Performance varies a lot from the other screws in the test being much worse compared to the other tested screws.

TABLE 5. *Results of the torque test for each screw type*

Number	**304 wax**	**304 Geomet**	**316 wax**	**304 Delta**	**Fe zn**	**304 Zintek**
	1	2	3	4	5	6
1	3.8	7.11	5.54	5.92	7.9	7.51
2	4.18	5.95	6.22	8.65	8.18	7.61
3	5.43	5.51	6.41	6.22	10.3	7.72
4	6.18	6.56	7.09	5.73	9.49	8.73
5	7.24	10.19	4.65	8.27	10.13	7.43
6	4.69	7.88	5.95	5.54	9.49	7.21
7	4.73	7.25	5.93	7.88	9.67	8.18
8	6.09	6.88	5.65	7.79	10.13	6.02
9	6.37	6.16	5.54	7.96	11.79	7.7
10	6.69	8.33	4.46	8.14	11.06	8.47
11	4.05	7.53	4.92	7.99	8.92	8.89
12	5.17	8.65	5.51	7.81	8.83	7.9
13	5.67	7.77	5.54	8.09	7.42	7.25
14	5.3	6.62	5.65	8.92	8.14	6.36
15	4.3	7.07	5.81	7.9	13.63	10.23
16	6.02	7.7	2.97	7.22	8.51	8.6
17	6.53		5.26	6.55	8.58	6.41
18	5.45		3.99	8.17	8.27	5.4
19	5.3		5.06		9.39	8.09
20	4.45				10.41	5.85
Average	**5.38**	**7.32**	**5.38**	**7.49**	**9.51**	**7.58**

TABLE 6. *Standard deviation in torque test*



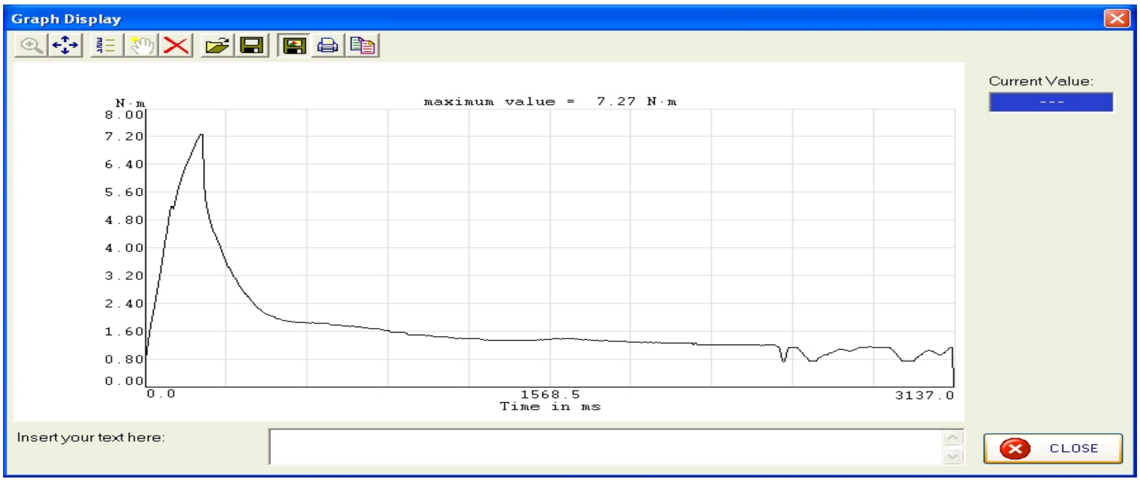


FIGURE 12. *SUS304 waxed M6x30*

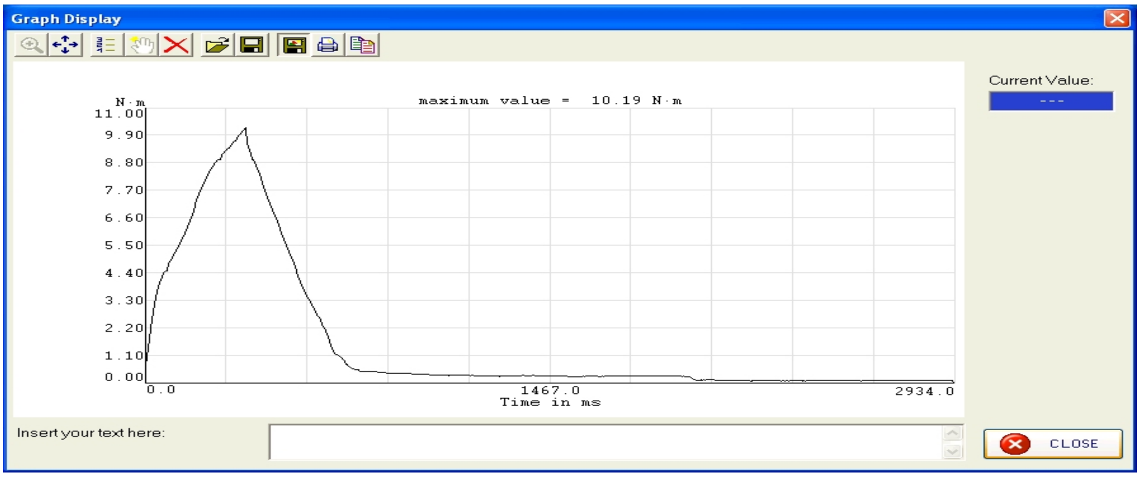


FIGURE 13. SUS304 Geomet M6x30

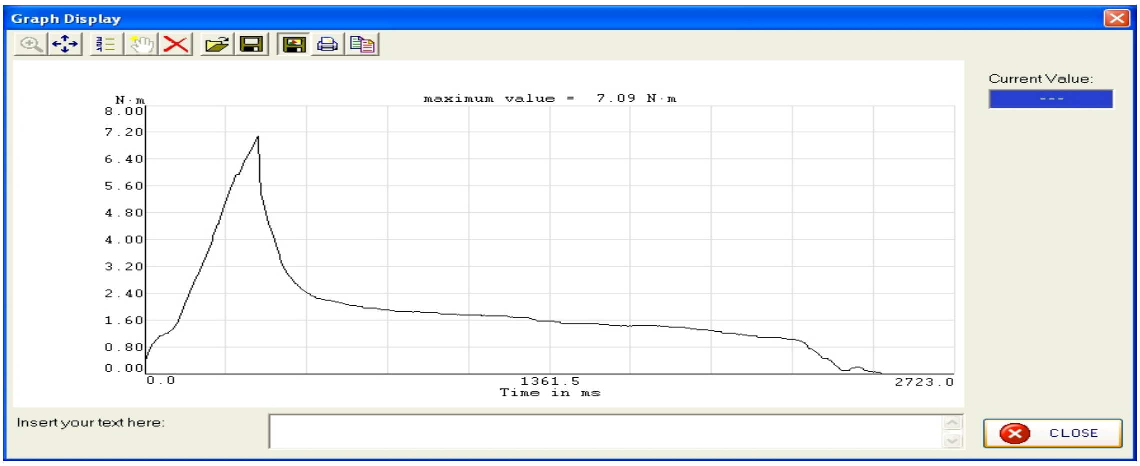


FIGURE 14. *SUS316 waxed M6x30*

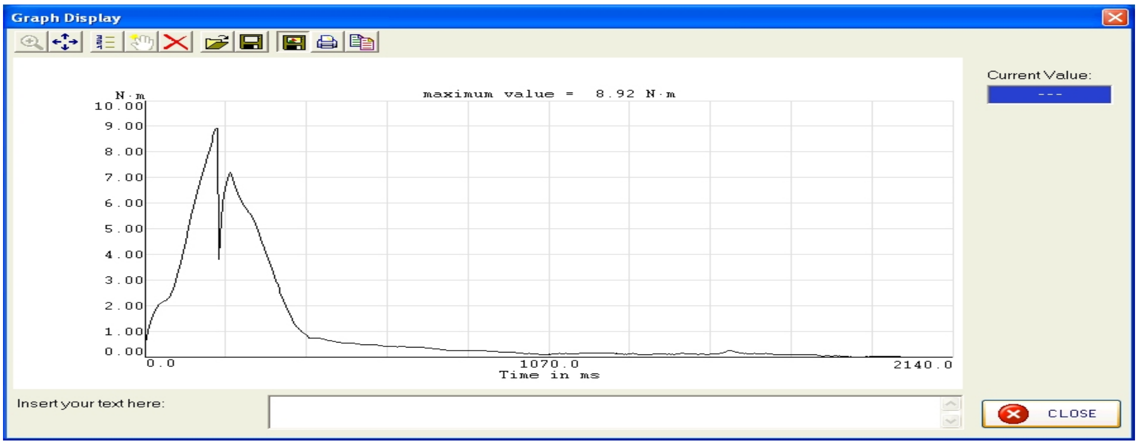


FIGURE 15. *SUS304 Deltatone M6x30*

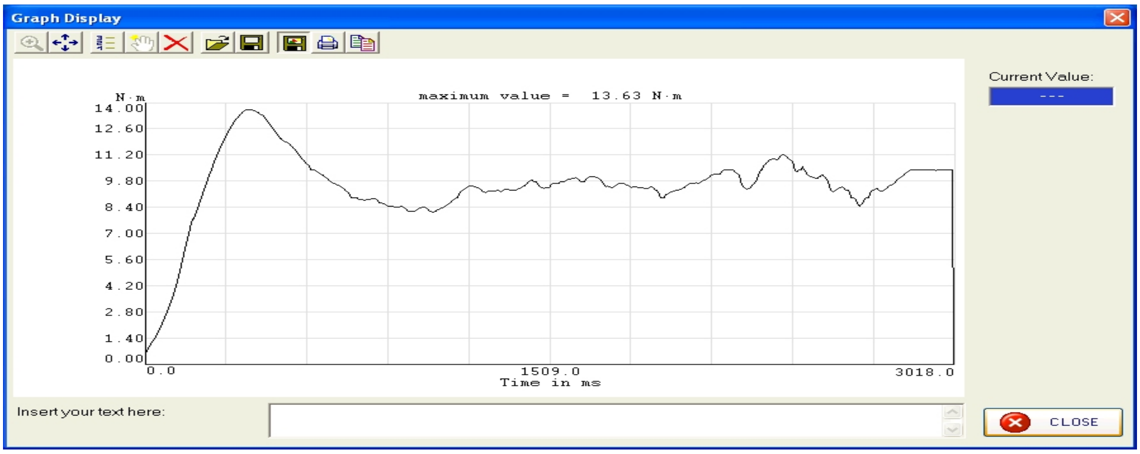


FIGURE 16. *10B21 Zn M6x30*

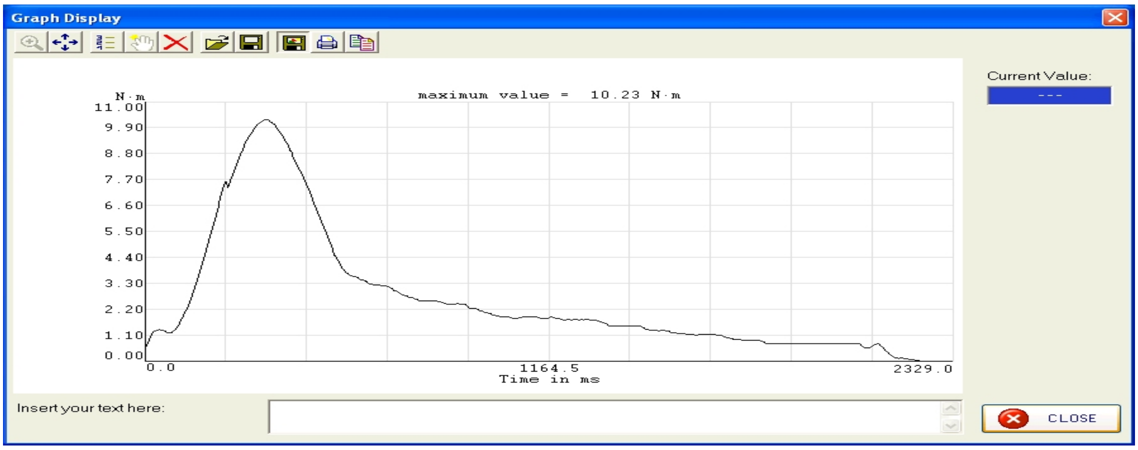


FIGURE 17. *SUS304 Zintek 200 + Top L M6x30*

As a comparison figure 18 shows the graph, when the ultimate strength has been achieved. The test has been done with A2/SUS304 – screw. With this figure it can be shown how close the breakage has been with the tested screws. In this test thread has been stuck on purpose and the screw has been opened to the ultimate strength point. The highest value achieved in the torque test was 13.49 Nm with 10B21 Zn screw.

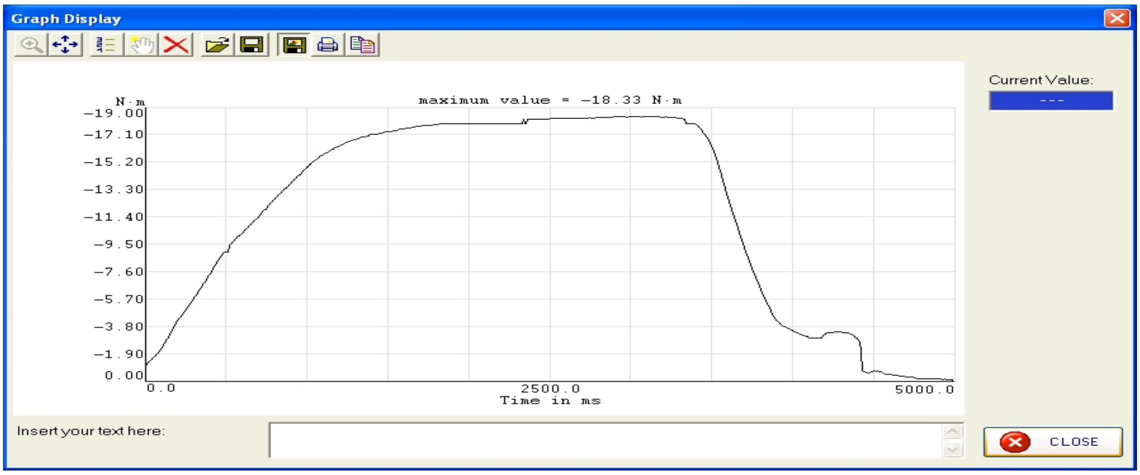


FIGURE 18. *Graph in ultimate strength*

In figure 18 it can be seen that yield starts in 15 Nm. By calculating normal distribution based on torque average and standard deviation it can be seen what are the risks for breakage of the screw in larger volumes. Based on the table it can be stated that the risk of the breakage of the screws is very low.

TABLE 7. *Probability of the screw breakage*

Yield Strength (Nm)	15	15	15	15	15	15
Breaking probability	0.00000 %	0.00000 %	0.00000 %	0.00000 %	0.01048 %	0.00000 %

6 CONCLUSION

As a conclusion it can be said that the screws already in use were passing the tests properly. This was expected as those have been in used in harsh environments and there is information about the performance in the field. The screws already in use in Nokia are SUS304 waxed, SUS304 with Geomet coating and SUS316 waxed. There were no significant issues in the visual testing or in the torque test. The screws were opened properly without disturbing friction in the rotation.

The new screw types with the new coatings were SUS304 with Delta Tone coating, 10B21 Zn and SUS304 with Zintek coating. There were some variable results among the new screw types. In SUS304 with Zintek coating there was no significant issue with the visual or torque test. The screw opened properly without friction. Situation was a bit different in the torque with SUS304 with Delta Tone. Some signs of friction can be seen in the screw thread. Also in the visual inspection a spot of corrosion can be seen in the aluminum thread. In the screw 10B21 failure in the visual – and torque test can be seen. The torque values are clearly the highest and there are visible signs of the starting corrosion in all three areas of the figures.

Based on the test results it can be said that all screw types already in use (SUS304 waxed, SUS304 Geomet coating and SUS316 waxed) passed the tests properly after the salt spray test. In other words screw selections have been correct and usage of those products can be continued in any product or environment.

In the new tested screw types (SUS304 Delta Tone coating, 10B21 Zn and SUS304 Zintek coating) situation is not that clear. The screw type, which can be recommended, is SUS304 with Zintek coating. There were some doubts with SUS304 Delta Tone due to possible spot of corrosion and signs of friction in the thread. Due to the red spot found, some special checking was conducted. Some samples were randomly taken and more threads were visually inspected. In this inspection no signs of other corrosion spots were found. It can be stated that the red spot found was caused by external, not exactly known, factor. Based on the additional tests this screw can also be recommended to use. Zn – screw can be clearly ruled out. It failed in all areas in the tests and is not an option as a new screw type to use. This failure also underlines the correct material selection in the screws used in the field.

Finally it can be said that the conducted tests support the original purpose. The purpose of the tests was to find out, whether we have selected the right screws to the products and can those selections be challenged with other options. Based on the test results it can be said that current screw selections secure adequate quality and functionality in challenging environment. However, part of the new screw options passed the test properly and will widen the selection of the screw types in use

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