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Analysis of the Surface Protection of a Maritime Object, Case Study

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ABSTRACT: In the maintenance of maritime facilities, one of the most common task is painting, that is, applying a protective hard coating to surfaces that are exposed to corrosive action. One of the main goals of painting and corrosion protection is to provide the most economical protection of structures. This paper presents the assessment of damage to the structure from the process of corrosive action, the control measurement of surfaces after the removal of corrosive deposits in order to reach the conclusion that the surface is ready for paint application. The measurements are listed in tables and are used for statistical analysis and the creation of control charts. These measures help to decide the potential process capability and also indicate by how much the tolerance limits exceed the actual distribution limits and whether further improvements are required. The control charts and the QI Macros software were the basic statistical tools used. In summary, the control charts provide the opportunity to take timely action to eliminate the cause of the defect within the process in order to minimise costs instead of remedying the consequences of the defect.

1 INTRODUCTION

All elements, compounds and substances in nature strive to reach the most stable form, the so-called ground state. In this state they have the highest stability and the lowest energy. Iron (Fe) is a stable element when analysing its structural stability and nuclear stability, but it is not stable on a chemical level under normal atmospheric conditions. In nature, under normal atmospheric conditions, iron will try to take on a more stable form, leading to corrosion. According to the Standard Terminology and Acronyms Relating to Corrosion, the definition of corrosion is "the deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment" [1]. According to the Wartsila Encyclopaedia of Ship Technology, corrosion is "the process of deterioration of metals and their properties, following a reaction with surrounding environment" [2]. The same encyclopaedia also states that "it readily oxidizes in moist air" [2]. To summarise, iron corrosion is a normal, natural process in which oxygen and water from the atmosphere help the iron to form more chemically stable forms, such as oxides.

Objects in the maritime industry are exposed to high relative humidity, chlorides, temperature fluctuations, different weather conditions and sometimes other forces of nature [3]. These harsh conditions and heavy use can degrade components and materials much faster than in land-based industries [4,5]. Therefore, protective measures must be taken to protect materials and equipment from these influences and thus from deterioration. A statement on the most commonly used protective measure was made more than seventy years ago: "Paint has been used for a long time for the protection of metals against corrosion" [6]. Originally, paint served as a barrier against the hostile

environment that surrounded the metal. Nowadays, paints are much more than that [7,8], they are created as electrical insulators that form a layer of electrical resistance, they also contain soluble pigments that are used to passivate the metal surface, and finally, paints today serve as an additional anode for the dissolution process [8].

The above shows the progress that has been made recently in the protection of materials by coatings. All this has been accompanied by corresponding recommendations, rules and regulations [9,10], which have also changed over time. These conditions have an impact on the present research, which is carried out on a submerged object subject to these strict control requirements.

The preparation of the area to be painted and the process of painting steel objects submerged in the sea depend on many different factors. They are illustrated in the fishbone diagram (Ishikawa diagram) in Figure 1.

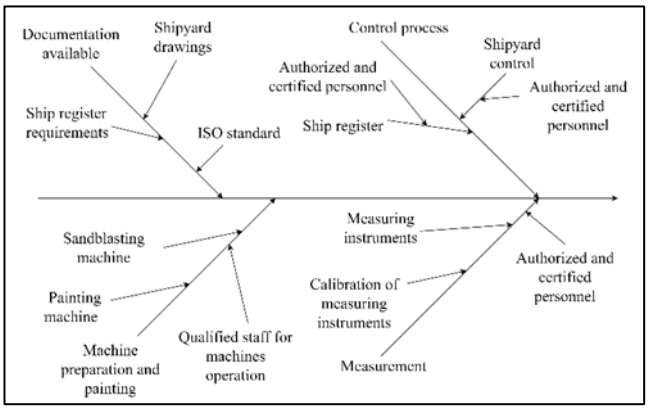


Figure 1. Paint preparation and application diagram

One of the aims of this research work is to demonstrate a fast, high-quality solution that is easy to apply under real conditions using control charts. Control charts were first developed and applied by Walter Shewhart [11], who used them to monitor the current state of the process and to predict future process phases (published in 1931 in the book "Economic Control of Quality of Manufactured Product") [12]. These charts are still referred to as Shewhart charts. After him, the development of statistical control was continued by authors like Deming [13], Juran [14], Ishikawa [15] and others up to the present day. This method was developed and linked to statistical software packages that enabled the selection, creation and analysis of control charts from measurement data, such as SPC (Statistical Process Control), DMAIC (Define, Measure, Analyze, Improve and Control) [16], and QI MACROS (EXEL support) [17]. Unlike laboratory measurements where the conditions are controlled, statistical control in control charts takes place due to its simplicity and precision in representing the data during the measurement process of the actual conditions on the measured object, which allows control and correction within the specified limits.

2 CONDITION ASSESSMENT OF EXISTING SURFACE COATING SYSTEM

Before deciding on the necessary surface repairs, it is essential to assess the condition of the surfaces. This is usually done based on experience and with the help of the manual for assessing the condition of hard coatings [18]. For the assessments of the „degree of effectiveness“ of an existing surface coating, it is suggested that the following „rating“ be used (explained in Table 1):

- GOOD condition with only minor spot rust.
- FAIR condition with local breakdown at the edges of stiffeners and welded joints and/or slight rust on 20% or more of the surfaces considered, but less than defined for POOR condition.
- POOR condition with general breakdown of coating on 20% or more of the surfaces in question or with hard scaling on 10% or more of the surfaces in question.

Table 1. Definition of coating condition [19]

Rating / Condition	Good	Fair	Poor
Spot rust	Minor	> 20%	
Light rust	Minor		
Edges, Weld	< 20%	> 20%	
Hard scale	Minor	< 10%	> 10%
General breakdown	Minor	< 20%	> 20%
Other references			
ISO	RI3	RI4	RI5
European Rust Scale	RE3	RE5	RE7

Note: The lowest rating within any category shall govern the final rating.

An example of an „Assessment Scale for Breakdown“ of coatings is shown in the following figures. The condition of the coating should normally be assessed over large areas. Figure 2 shows a coating in good condition. The condition shown corresponds to the criteria given in Table 2, i.e. the criteria for the evaluation of this example.

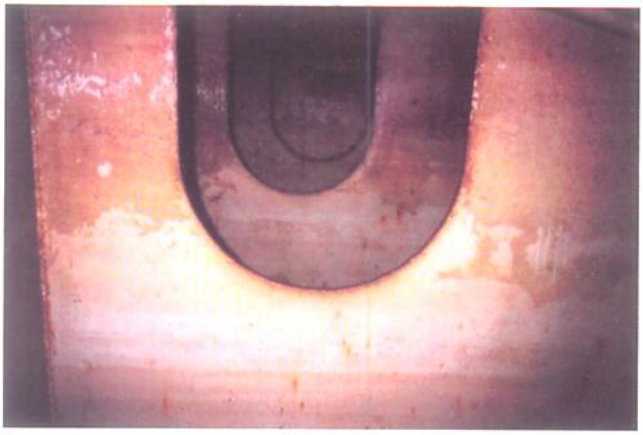


Figure 2. Coating in GOOD condition [20]

Table 2. Explanation of Coating condition GOOD [20]

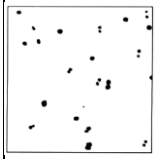
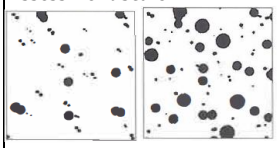
Notes:	Assessment scale
1. Minor rusting on weld seams. 2. Spot rusting. 3. Filmy deposit mush of surface.	 Less than 1%

Figure 3 shows a coating in fair condition. The condition shown corresponds to the criteria given in

Table 3, i.e. the criteria for the evaluation of this example.

Figure 3. Coating in FAIR condition [20]

Table 3. Explanation of Coating condition FAIR [20]

Notes:	Assessment scale
1. Anode working 2. White deposits 3% 3. Corrosion on edges 4. Top coat loss.	 5% 10%

The poor coating condition is described in the same way as the two previous conditions. Figure 4 shows a coating in poor condition. This condition is described in detail in Table 4, i.e. the criteria for evaluating this example are listed there.

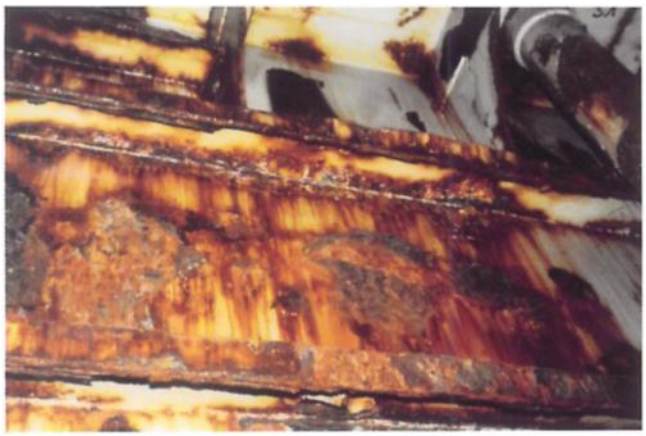
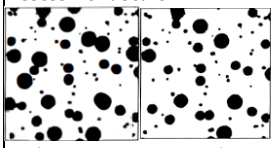


Figure 4. Coating in POOR condition [20]

Table 4. Explanation of Coating condition POOR [20]

Notes:	Assessment scale
l. Corrosion >20% 2. Hard scale >10% 3. Deformed stiffener edges	 20% 10%

Once the condition of the paint has been checked against the above criteria, the surfaces to be painted are inspected and measured.

3 MEASUREMENTS AND ANALYSIS DESCRIPTION

The measurements were carried out on the surface of the object in two runs, before and after painting. The measurements are listed in tables and are used for statistical analysis and the creation of control charts. The statistical methods include the following steps: Measurements, data processing and presentation, analyses and interpretations of the values obtained. These measures help to arrive at a decision on the potential process capability (*Cp*) and also indicate by how much the tolerance limits exceed the actual distribution limits and whether further improvements are required.

The potential Cp is assessed on the basis shown in Table 5.

Table 5. Evaluation of potential process capability

$Cp = \frac{\text{USL-LSL}}{6\sigma}$	Potential process capability
$Cp > 1.33$	Process has potential to be capable
$1.0 < Cp > 1.33$	Possible capability is questionable, and the process should be monitored
$Cp < 1.00$	Very questionable potential process capability
$Cp_U = \frac{\text{USL-}\bar{X}}{3\sigma}$	Upper specification limit of potential process capability
$Cp_L = \frac{\bar{X}\text{-LSL}}{3\sigma}$	Lower specification limit of potential process capability

* σ - Process standard deviation, a measure of process variability

According to the data presented, *Cp* can be assessed as capable, with questionable capability and with very questionable capability. The process tolerance shows how the measured values fulfil the standards (tolerances) by which the process is determined.

Table 6. Evaluation of process tolerances

$Cp_k = \min(Cp_U, Cp_L)$	Demonstrated excellence
$Cp_k > 1$	Process tolerance within limits
$Cp_k = 0$	Mean value is equal to one of the tolerance limits
$0 < Cp_k < 1$	Process tolerance exceeds limits
$k = 0;\ Cp_k = Cp$	Process is perfectly centered

The Cp_k value according to Table 6 indicates how centred the process is, i.e. the position of the process (measured values) in the tolerance field, and shows the accuracy of the process by monitoring the lowest value. The average of the mean values is often not centred, which is why the capability index is used to indicate the position of the values, i.e. the mean value and the process deviation. The correlation between *Cp* and Cp_k can be expressed mathematically as follows:

$$Cp_k = Cp(1-k) \quad (1)$$

The value "*k*" indicates the shift of the process, i.e. its values, from the centre when the process (the measured values) is perfectly centred.

$$k = \frac{\left| \frac{USL - LSL}{2} - \bar{X} \right|}{\frac{USL - LSL}{2}}; \qquad 0 < k < 1 \tag{2}$$

The upper specification limit (USL) and the lower specification limit (LSL) are determined by the ISO standard, while the lower control limit (LCL) and upper control limit (UCL) are calculated within an interval of ±3σ. The control limits are not related to the tolerance limits as they are determined by the process itself. The standard deviation is used as a measure of the amount of dispersion in control charts. The values obtained through data analysis are as follows:

- The upper specification limit (USL),
- The lower specification limit (LSL),
- Average, i.e. mean value,
- Standard deviation (Stdev).

The process is kept within the defined limits by constant monitoring. For this reason, control charts are used to represent data and are part of the statistical control process as well as an efficient means of obtaining information and making a quick and high-quality decision regarding the process. If the value rises or falls seven points in a row, a trend is created and the process is not stable, even if all the data is within the upper and lower limits. If the value rises or falls by five consecutive points, resulting in a trend, the process is in a critical state but is still stable. An increased critical state signals the transition of the process to an unstable state. Two or three points above 2σ should be a warning if the values are within the control limits. This is due to a change in equipment, measurement procedure or method. A stable process is one in which all results, or at least a satisfactory number of results, are within the control limits. To ensure high quality and accurate monitoring of all stages of the process, three statistical methods were used: control charts (X and mR), histograms and mathematical distribution analysis.

4 MEASUREMENTS AND ANALYSIS PRIOR TO PAINTING

Control measurements before painting are used to determine whether the surface is prepared to meet the requirements. The process begins with fresh water cleaning, degreasing and sandblasting (or hydro blasting) to achieve a surface cleanliness level of Sa3 in accordance with the international standard ISO 8501-1:2007 [21]. After cleaning, the surface is protected by a two-component zinc silicate coating, for which there are many different manufacturers on the market today. All equipment on the object, whether welded (beams, clamps) or connected (pipes), must be blasted to the Sa 2.5 level. Control measurements are then carried out, which are listed in Table 7.

Table 7. Control measurements before painting

No	ROUGHNESS Rz (μm)	SALT CONCENTRATION (mg/m²)
1	82.55	21.525
2	83.55	21.700
3	76.75	21.925
4	85	18.375
5	84.7	18.175
6	80.75	17.850
7	78.9	26.800
8	83.6	26.775
9	84.55	16.975
10	74.8	16.950
11	82.1	23.900
12	85	23.900
13	71.2	14.775
14	84.75	14.800
15	83.5	14.900
16	84.25	19.975
17	77.25	19.950
18	75.75	23.925
19	81.25	24.050
20	78.5	24.075

These measurements are used to check the condition of the surface before applying protective coatings. Two main areas of the control are roughness control and analysis and salt concentration analysis.

4.1 *Roughness control*

Microscopic roughness is an irregular surface caused by the treatment of a material. Since surface roughness accelerates the corrosion process, the surface should be protected by a coating. Before applying a protective coating, the surface must be prepared, i.e. it must be free of: rust, scale, dust, salts and fats. The assessment is carried out in accordance with ISO standards 8501 [22], 8502 [23,24] and 8503 [25], while ISO 8504 [26] contains guidelines for the preparation of steel surfaces, i.e. for achieving a certain degree of cleanliness. After cleaning, the surface is classified as follows: fine, medium and rough. These gradations represent different degrees of roughness, depending on the required quality. The individual roughness grades are defined in ISO 8503, while ISO 8503-1 [25] specifies the measuring device for measuring the surface. Figure 5 shows the surface after sandblasting the inner surface and before applying the protective coating.

Figure 5. Sand blasting of the inner surface [16]

When sandblasting, the abrasive must be dry and clean and must not be contaminated, as this would jeopardize the quality of the surface before the paint is applied. When using abrasives, i.e. sandblasting, the

size of the particles creates a roughness of at least 30 µm to a maximum of 85 µm. According to the ISO 8503 standard [25], these are acceptable roughness limits.

Using the data from Table 7 and the QI Macros program, Figure 6 is created.

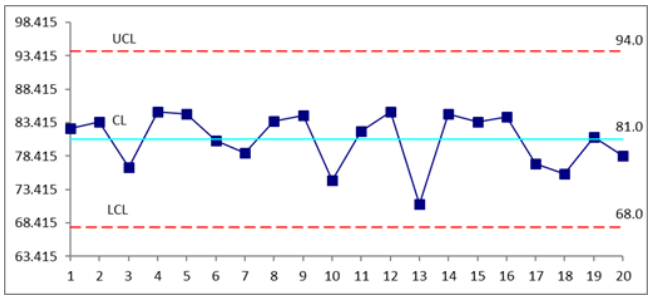


Figure 6. X chart of the roughness mean value

Figure 6 is showing an X-chart of the roughness value. i.e. the mean value. It is consistent across all measurements and is within the UCL and LCL (upper and lower control limits) for all measurements. The same sources and methods are used to create Figure 7, which shows the mR chart of the roughness mean value. The moving range of consecutive observations shows that there are no significant deviations in surface roughness. All measured data are within the limit values and no trends can be identified.

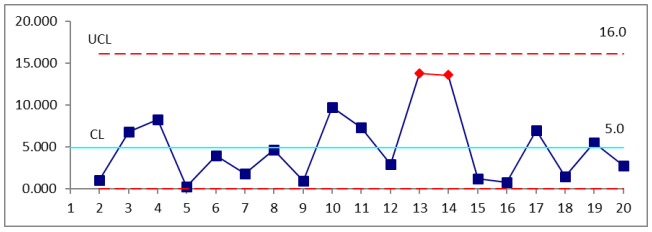


Figure 7. mR chart of the roughness mean value

The mR chart shows only two points above the average value, but still within the limit values. The process is therefore stable.

The regression analysis of the roughness measurements is shown in Figure 8, from which it can be seen that the roughness measurements correspond to the probability diagram of the normal distribution.

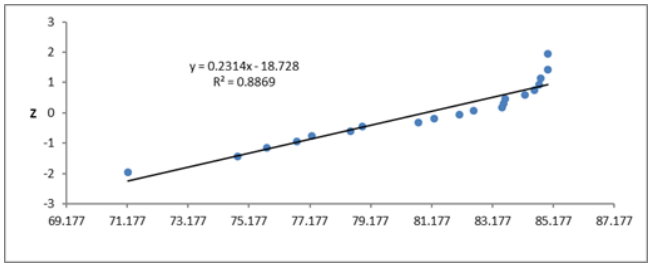


Figure 8. Regression analysis of roughness measurements

Figure 8 shows that the roughness measurements are consistent with the probability plot for the normal distribution. The probability plot for the normal distribution shows a strong linear positive correlation, represented by the line Y=0.231X-18.72. There are only minimal deviations from the regression line, which leads to the conclusion that the normal distribution is a well-chosen model for the roughness measurement. The coefficient of determination shows that 88.6% of all deviations are interpreted by the linear regression model, so that the correlation is very well interpreted by the regression. This confirms that the roughness model is representative.

The standard value Z in Figure 8 indicates the relative position of the data and is calculated according to Equation 3.

$$Z = \frac{X - \bar{X}}{\sigma} \tag{3}$$

The estimation of the potential process capability Cp and the demonstrated excellence Cp_k, which were determined using statistical analysis and the QI Macros programme package for roughness measurements, are shown in Table 8.

Table 8. Control measurements before painting

USL	85	Upper specification limit
LSL	30	Lower specification limit
Average	80.935	Arithmetic mean
Cp	2.27	Process is capable
CpU	0.33	Upper potential process capability
CpL	4.20	Lower potential process capability
Cpk	0.33	Process tolerance exceeds limits
Stdev	4.05	Standard deviation

The results of the roughness measurement are shown in the histogram and in the normal distribution, as can be seen in Figure 9.

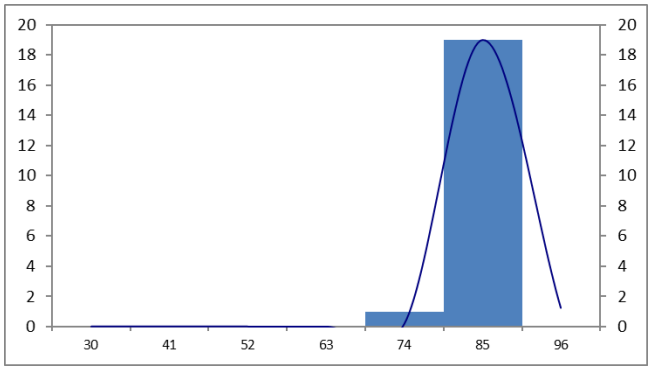


Figure 9. Roughness measurement histogram

The histogram and normal distribution for the roughness measurements in Figure 9 show that the values are close to the upper limit given in Table 8.

4.2 *Dust and salt concentration*

Rust, salt, dust, fats and other contaminants that fall on or come into contact with the surface affect the cleanliness of the surface before the paint is applied. Such surfaces are cleaned by sandblasting and degreasing. If dust particles remain on the surface and a coat of paint is applied, cracking and subsequent corrosion can occur. For this reason, it is extremely important to clean and inspect the surface as well as possible to ensure optimum contact between the paint and the surface. The rules for monitoring the surface for salt and dust are laid down in ISO 8502 [23,24]. According to the ISO 8502-3 [24] standard, the dust on the surface is monitored and graded from 1 to 5. The maximum permissible amount of dust on a surface is 2. If this limit is exceeded, the surface must be cleaned additionally and measurements must be taken until a satisfactory level is reached.

The actual dust and salt measurement for this analysis is carried out on a steel surface before applying a coat of paint using a pressure-sensitive adhesive tape, which is shown in Figure 10.

Figure 10. Dust measurement

After removing the adhesive tape, a visual inspection is carried out and compared with the etalon. The standards ISO 8502-6 [27] and ISO 8502-9 [28] describe the procedure for measuring the salt concentration on a surface, whereby the preparation of the measuring device is carried out in accordance with ISO 8502-6 [27]. The surface density of the salt is calculated according to the ISO 8502-9 [28] standard.

As already mentioned, the measurements are carried out in accordance with ISO standards 8502-6 and 8502-9, which stipulate that the chlorine salt content must not exceed 30 mg/m2. As shown in Figure 11, the "Bresle Method" is used for measurement and the value of soluble salts is 27.6 mg/m2. This value is within the limit values according to ISO standards 8502-6 and 8502-9 [27,28].

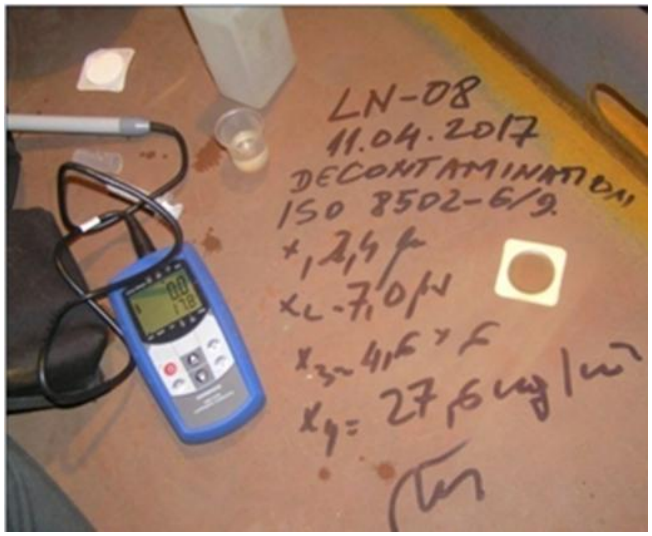


Figure 11. Salt measurement

In this case, as in the previous analysis, the data from Table 7 were used to generate control charts X, mR, probability paper, histogram and normal distribution curve for the measured salt concentration values using the QI Macros programme package.

Figure 12 shows considerable deviations in the salt concentration measurements.

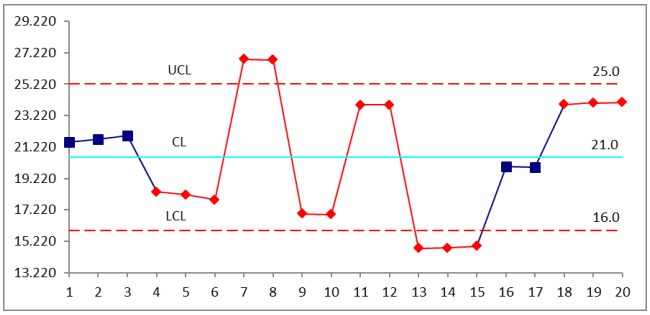


Figure 12. X chart of the salt concentration mean value

All of the measured data on the X-chart are within the upper UCL and lower LCL limits, but with the exception of two values that are above the UCL and three values that are below the LCL, there is no trend in the measured data obtained.

Since the measured values do not exceed the limits specified in the ISO standard, it can be concluded that the system should be closely monitored, which is confirmed by the mR diagram shown in Figure 13.

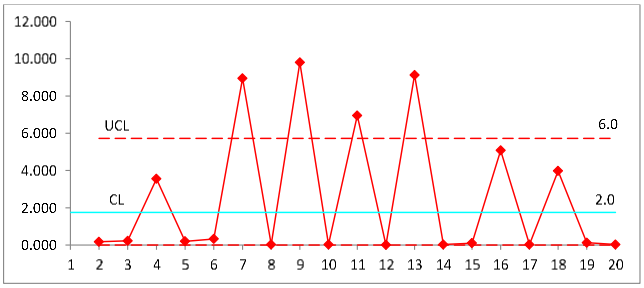


Figure 13. mR chart of the salt concentration mean value

The figure shows that only four values are above the upper UCL limit. These results indicate that the process needs to be improved, i.e. the surface should be better cleaned of salt or better protected.

The regression analysis of the salt concentration data on the probability plot for normal distribution is shown in Figure 14.

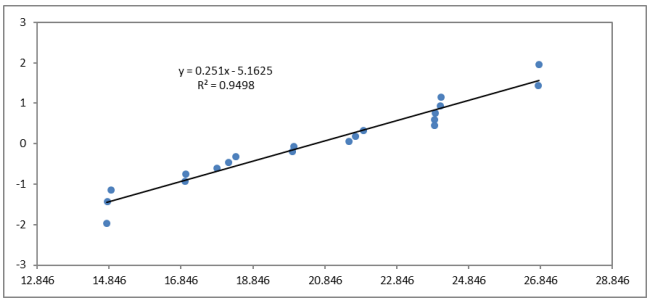


Figure 14. Regression analysis of salt concentration

It shows that the surface salt concentration measurements fit best with the probability plot for normal distribution. This normal distribution probability plot shows a strong linear positive correlation, represented by the line Y=0.251X-5.162. There are only minimal deviations from the regression line, which leads to the conclusion that the normal distribution is a well-chosen model for roughness measurement. The coefficient of determination shows that 94.9% of all deviations are interpreted by the linear regression model, so that the correlation is very well interpreted by the regression.

This confirms that the surface salt concentration model is representative. Overall salt concentration measurement analysis results are given in Table 9.

Table 9. Salt concentration measurement analysis results

USL	30	Upper specification limit
LSL	0	Lower specification limit
Average	20.565	Arithmetic mean
Cp	1.30	Potential capability is questionable, and the process should be monitored
CpU	0.82	Upper potential process capability
CpL	1.78	Lower potential process capability
Cpk	0.82	Process tolerance exceeds limits
Stdev	3.86	Standard deviation

The measurements of the surface salt concentration are shown in the histogram and in the normal distribution and reproduced in Figure 15.

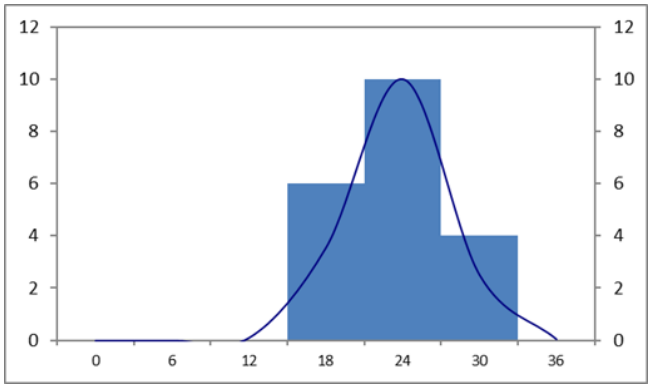


Figure 15. Salt concentration measurement histogram

It can be seen that the values are close to the upper limit, which are listed in Table 9.

5 PAINTING

Once the surface preparation and cleaning have been completed, the surface is ready for the paint application, as shown in Figure 16. The paint must be applied in accordance with the paint manufacturer's recommendations, which comply with the ISO 2808 [29] standard, and the requirements for weather conditions must be strictly observed.

If the paint is applied within 8 hours of surface preparation, the following conditions must be met: The temperature difference on the steel surface must be within the limits, i.e. between the minimum and maximum values, at least 3°C above the dew point and a maximum relative humidity of 85% [29].

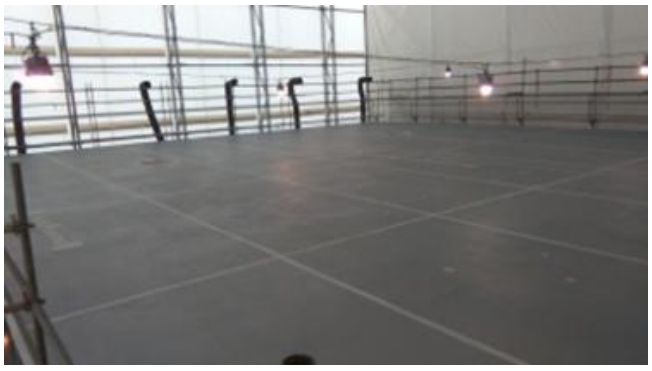


Figure 16. Surface before paint application

If the coating is applied more than 8 hours after surface preparation, the temperature difference on the steel surface must be between the minimum and maximum values, at least 5°C above the dew point and a maximum relative humidity of 40% (maximum 50 %) [29]. The atmospheric conditions must be measured during and after the application of the paint, which is why the object must be protected. Figure 17 shows the same surface as in Figure 16, this time after the paint has been applied in a protected environment.

Figure 17. Surface after paint application

Before, during and after the application of the paint, the parameters of the paint manufacturer and the ISO 2808 standard are checked by continuous condition monitoring.

6 MEASUREMENTS AND ANALYSIS AFTER PAINTING

The measuring devices must be tested on the test plate before the procedure, using the etalon that comes closest to the specified DFD (dry film density). The quality of the measurement depends on the following factors:

- Calibration of the measuring instrument,
- Testing the measuring instrument before each measurement,
- Additional adjustment of the measuring instrument, if necessary,
- Expertise of the operator.

The measurement data used for this research was obtained by measuring the coating thickness using the microscopic method, which comprises three procedures: A, B, C.

- Procedure A is a general method suitable for measuring variations in coating thickness on an uneven surface [30].
- Procedure B is used to measure film thickness above 2μm and on solid surfaces, as the film is cut at a specific angle [30].
- Procedure C uses a special microscope with an additional device to monitor the surface profile of the sample, and the method is performed on the part that is exposed to sufficient light to obtain a clear image in the microscope [30, 31], as shown if Figures 18 and 19.

Figure 18. Vertical coating thickness measurement

At the same time, care must be taken to ensure that the number of samples is representative for this method. The procedure is described in detail in ISO standard 1463 [19].

When measuring, attention should be paid to coatings with high elasticity, as the elasticity influences the accuracy of the measurement results. To successfully measure the thickness of opaque coatings, a small area of the coating must be removed.

Figure 19. Horizontal coating thickness measurement

The difference between the surface of the coating and the surface of the object leads to a deflection of the light beam and thus to an absolute measurement of the coating thickness. The measured values are listed in Table 10.

Table 10. Control measurements before painting

No	ROUGHNESS *Rz* (µm)	SALT CONCENTRATION (mg/m²)
1	82.55	21.525
2	83.55	21.700
3	76.75	21.925
4	85	18.375
5	84.7	18.175
6	80.75	17.850
7	78.9	26.800
8	83.6	26.775
9	84.55	16.975
10	74.8	16.950

The data measured after painting, shown in Table 6, were used to obtain control charts X, mR, probability paper, histogram and normal distribution curve for the measured coating thickness values using the QI Macros programme package. This is done according to the same principles as the analysis of the data obtained before painting.

Figure 20 shows the deviations in the layer thickness measurements. All measured data on the X-chart lie within the upper UCL and lower LCL limits, with the exception of one value that lies below the LCL.

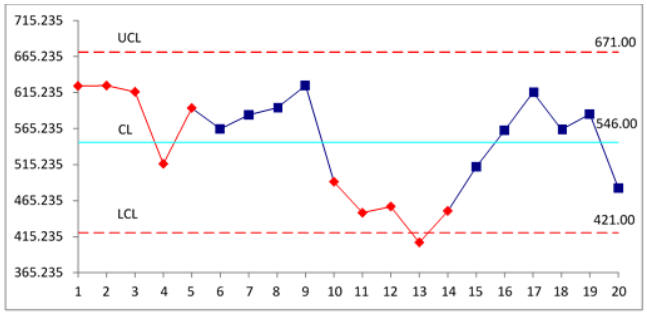


Figure 20. X chart of the coating thickness mean value

The mR chart shown in Figure 21 shows five points that form a trend indicating a critical condition, i.e. special care must be taken when applying the coating.

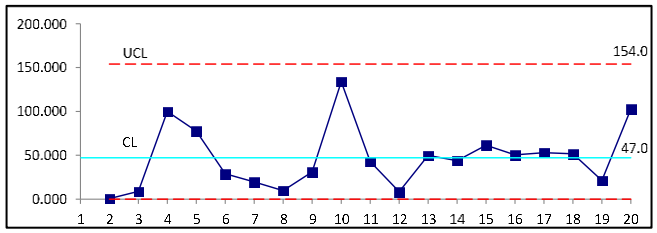


Figure 21. mR chart of the coating thickness mean value

Since the measured values do not exceed the limits specified in the ISO standard, it can be concluded that the system should be closely monitored and the process of applying paint to the section surface should be improved.

The regression analysis of the coating thickness data on the probability plot for normal distribution is shown in Figure 22. It shows that the measurements of the coating thickness correspond best to the probability diagram of the normal distribution. This probability plot for the normal distribution shows a strong linear positive correlation, represented by the line Y=0.013X-7.458. There are only minimal deviations from the regression line, which leads to the conclusion that the normal distribution is a well-chosen model for the coating thickness measurement.

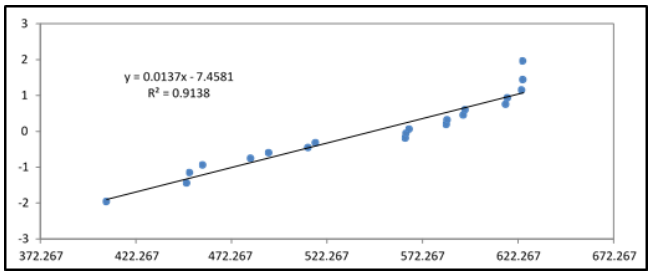


Figure 22. Regression analysis of coating thickness

The coefficient of determination shows that 91.3 % of all deviations are interpreted by the linear regression model, so that the correlation is interpreted very well by the regression. This shows that the coating thickness model is representative. Overall coating thickness measurement analysis results are given in Table 11.

Table 11. Control measurements before painting

USL	625	Upper specification limit
LSL	400	Lower specification limit
Average	546.055	Arithmetic mean
Cp	0.54	Very questionable potential process capability
CpU	0.38	Upper potential process capability
CpL	0.70	Lower potential process capability
Cpk	0.38	Process tolerance exceeds limits
Stdev	69.57	Standard deviation

The measurements of the coating thickness are shown in the histogram and in the normal distribution and reproduced in Figure 23.

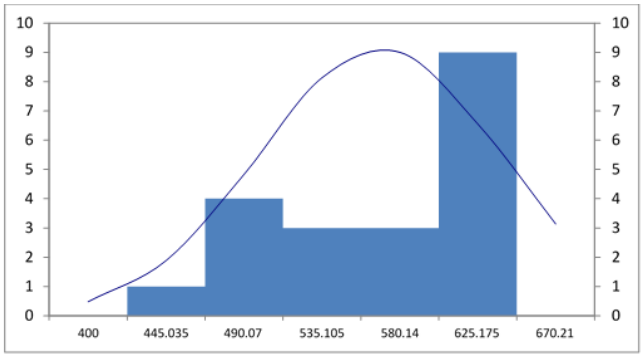


Figure 23. Coating thickness measurement histogram

Figure 23 shows the histogram and the normal distribution for the coating thickness measurements, clearly showing that the values are close to the upper limit given in Table 11.

7 CONCLUSIONS

In this work, an attempt was made to improve the quality of the preparation and the monitoring of the parameters that influence the quality of the painting process. To achieve this goal, a statistical analysis was used to allow continuous monitoring and improvement of the process. The control charts and the QI Macros software were the basic statistical tools used. As part of the statistical analysis, the control charts track whether the data complies with ISO standards and indicate corrective actions if it is not within the limits. This is a great help to the manufacturer as it improves the monitoring process and the quality of production. At the same time, the ISO standards and the rules and regulations of the classification societies are met. The example used in this research shows that the control charts indicate that the salt concentration on the surface must be closely monitored and that the surface should be checked and cleaned more frequently. At the same time, the roughness and coating thickness are within the specified limits.

In summary, the control charts provide the opportunity to take timely action to eliminate the cause of the defect within the process in order to minimise costs instead of remedying the consequences of the defect.

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