Coating System for Infra Structural Works

Andreas Heutink, B.Sc., Willem Bonestroo, Jo van Montfort B.Sc.

Ministry of Transport, Public Works and Water Management, “Rijkswaterstaat”,
Civil Engineering Division, P.O.Box 20.000, 3502 LA UTRECHT, The Netherlands

Summary: “Rijkswaterstaat” is a government organisation responsible for the construction, operation and maintenance of a large number of structures. The organisation consist of a general engineering division and a number of regional offices responsible for the Rijkswaterstaat objects in their particular region. Rijkswaterstaat spends between 40 to 50 K€ per year on coating and coating related activities. When the steel structures of the Eastern Scheldt barrier (± 200,000 m^2 of steel) were coated in the mid eighties the applied high solid epoxy system developed extensive cracking. This resulted in numerous locations with pit corrosion. Investigations were carried out and it was concluded that the cracking of this specific high-solids epoxy system was caused by restrained shrinkage. This resulted in the build up of high internal mechanical stresses in the coating system. Problems with stress build up were also encountered on other projects, although less severe and mainly concentrated at edges and welded joints.

To prevent future problems, RWS has taken a number of initiatives such as the developed a procedure for the selection of coating systems. This selection procedure has proven to be useful for RWS in selecting coating systems for use on infra structural works.

The basic principle of the selection procedure of the RWS selection procedure is different from most other procedures. The RWS selection procedure uses the object to be coated as a starting point instead of the coating system. This is done by first evaluating all relevant aspects of the object which may influence the selection of a system. These aspects are then translated into so called “Functional requirements”. Coating systems with properties that are in compliance with the performance requirements are gathered and through comparison of requirements and properties a selection is made.

The objects that, until now, have been coated with systems selected with the selection procedure have performed adequately. Systems that have been selected with the procedure to replace or repair those that have developed cracking have until now not shown any new problems.

At the present time more and more alternative tests and test procedures become available, most of them derived from ISO 12944. These will be studied closely and compared with the currently used methods on the level of functional requirements.

RWS is already actively involved in the search for alternative test methods and will remain to do so in the future. In view of this the Rijkswaterstaat selection procedure will remain in function.

Keywords: Cracking, e-modulus, fingerprinting, functional requirements, high-solid epoxy-based coating systems, integral life cycle, mechanical stress, tensile strength, restrained shrinkage, rijkswaterstaat selection procedure, shrinkage, structural data, WOM Whether-O-Meter test

 CCC 1022-1360/00/$ 17.50+.50/0

INTRODUCTION

"Rijkswaterstaat" is a government organisation responsible for the construction, operation and maintenance of a large number of structures. These include all the major flood barriers that have been constructed in the Netherlands as well as a large number of bridges, tunnels and locks. Most of the objects are designed for a service life of 100 to 200 years.

The organisation consists of a general engineering division and a number of regional offices responsible for the Rijkswaterstaat objects in their particular region. Rijkswaterstaat spends between 40 to 50.000.000,- euro per year on coating and coating related activities.

Until just a few years ago, the steel structures of flood barriers in the Netherlands were usually coated with tar-epoxy coating systems. The tar-epoxies performed very well, but the use of tar is now prohibited in the Netherlands. The coating industry and the Dutch government have furthermore agreed that the emission of volatile organic compounds must be reduced in the coming years. This has prompted a major effort on the part of the coating industry to develop new coating systems which can meet the requirements and are more environmentally friendly.

When the steel structures of the Eastern Scheldt barrier (± 200,000 m^2 of steel) were coated, it was decided halfway through the project that the coal tar based system would be changed to a high solid epoxy system. Within a few years, the high solid epoxy system developed extensive cracking. This resulted in numerous locations with pit corrosion. At approximately the same time similar problems were noticed on other steel structures, although less severe and mainly concentrated at edges and welded joints.

Investigations have been carried out to establish the cause of the cracking of these high-solids epoxy-based coating systems.

The investigation showed that the cracking behaviour can be simulated using the accelerated Weather-O-meter test. It was concluded that the cracking of this specific high-solids epoxy system was caused by restrained shrinkage. The main cause of the shrinkage was due to evaporation of compounds during a stage, in which the coating system had already become fairly rigid. This resulted in the build up of high internal mechanical stresses in the coating system. Stresses were found to be highest in areas where transitions in coating thickness occur and changes are seen in the geometry of the structure. The level of stress and probability of cracking is high in these areas. Problems with stress build up were also encountered on other projects.

Since these defects have resulted in a significant amount of costly repair work it was decided that initiatives were needed to avoid further damage and costs in the future.

INITIATIVES

The initiatives taken by Rijkswaterstaat to improve on performance of protective coatings were:

- Design and implementation of a selection method for protective coating systems
- Improving contracts and specifications
- Development and implementation of maintenance strategies,
- Improving the standard of workmanship by taking part in an initiative for personal certification of painters, setting standards and implementing training for inspection personnel.

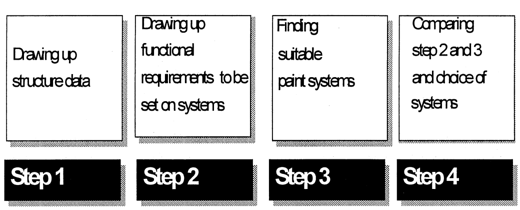
In this paper only the selection method for protective coating systems will be outlined and discussed.

BASIC PRICIPLE

The basic principle of the Rijkswaterstaat selection procedure is different from most other procedures. The RWS selection procedure uses the object to be coated as a starting point (instead of the coating system). This is done by first evaluating all relevant aspects of the object which may influence the selection of a system. These aspects are then translated into so called "Functional requirements". Coating systems with properties that are in compliance with the performance requirements are gathered and through comparison of requirements and properties a selection is made.

SELECTION PROCEDURE IN THEORY

The objective of the selection procedure is not to act as a "coating system select machine" but to support the selection process in a logical way so the most suitable coating system for the intended purpose can be selected. This selection is made in four steps. Selecting a coating system is trying to find a perfect balance between aspects such as environment, costs, lifecycle, application, maintenance strategy and product quality.



FOUR STEPS:

Step 1: Drawing up structural data

In step 1 all data relevant about the object to be coated is gathered. Typical data will include function of the object, its form (shape), type of exposure, esthetical aspects, substrate, maintenance, economic life time, etc. This data will be used in step 2 as the basis for the functional requirements of the protective coating to be selected..

Step 2: Drawing up functional requirements to be set on coating systems

Data of the object structure is translated into functional requirements for the coating system in step 2. The requirements that introduce a risk with respect to the selection of a coating system must be quantified or made quantifiable and measurable. Functional requirements will not only be test related but will also include requirements with respect to application properties, experience with a system, environmental considerations, etc.

Example:

If in step one it was found that the structure has a large number of very complicated details there is a significant risk of excessive film thickness being applied. This would be caused by a high degree of overlap during airless application. This aspect would then be translated into a functional requirement with respect to the tolerance in maximum allowed film thickness.

Step 3: Finding suitable coating systems

In step 3, matching functional properties are sought for the functional requirements drawn up in step 2. Data on the functional properties of protective systems must therefore be available. The data is generated through testing on the initiative of Rijkswaterstaat and/or is delivered by the coating manufacturers. The data does not only include test data but, even more important, data with respect to practical experience (references), application properties en environmental aspects.

Step 4: Selecting a system by comparing functional requirements and functional properties

In the fourth and final step, the functional requirements are compared with the functional properties of protective systems. The degree to which the properties match the requirements determines the selection of a protective system. Before considering whether a protective system meets the requirements, it must be determined whether the available data is complete. Incomplete data does not necessarily mean a system is unsuitable but introduces additional risks. Depending on the importance of a project and especially on the amount of indirect costs and risks in case of a premature coating failure, insufficient data may be accepted or additional data gathered for instance through testing or evaluation of additional references. Carrying out a more detailed investigation may result in new data, after which the information will have to be reconsidered.

SELECTION PROCEDURE IN PRACTICE

Step 1: Drawing up structure data

Since not all objects are completely unique, with respect to the aspects that influence the selection of a coating system, standard formats have been drawn up that cover the majority of aspects of the Rijkswaterstaat objects. These have been divided into the following three major categories;

- Atmospheric exposure with direct UV light, for instance topside of bridges.
- Atmospheric exposure without direct UV light for instance underside of bridges.
- Immersion service, for instance flood gates.

When a coating system has to be selected in step one an evaluation is made with respect to differences between the standard list of relevant aspects compared to the actual aspects of the object for which the system is to be selected.

Step 2: Drawing up functional requirements

The standard lists of aspects in step 1 have been translated into standard lists of performance requirements for the three mentioned categories. In case differences are found between the standard and an actual aspects during step one this may result in the addition of new performance requirements, altering of existing requirements or perhaps even omitting standard requirements.

Example:

In step one it was found that a structure had an existing coating system with micro cracking. This existing system had to serve as the substrate to which the new system would be applied and therefore differs from the standard Sa2 ½ blasted steel surface mentioned in the standard performance requirements for this structure.

The reason for applying a new coating system, in this particular case, was to prevent the micro cracking form developing into a much more serious type of cracking or even flaking. The anti corrosion properties would however still have to be realised by the existing system. (the substrate) Therefore there is no need for corrosion test data (salt spray test, immersion, etc.) and the functional requirements with respect to these were omitted. Given the nature of the problem additional requirements with respect to adhesion and mechanical behaviour on this specific substrate were however considered necessary. Additional functional requirements in the form of the standard WOM test have being carried out on a simulated cracked substrate (test panel) instead of the standard Sa2 ½ blasted steel panel were added to the lab test programme.

Step 3: finding suitable coating systems

Rijkswaterstaat has initiated a number of test programmes since 1994 to generate sufficient data with respect to the properties of various coating systems. Systems meeting the standard requirements of the three categories mentioned under step 1 are available for use on Rijkswaterstaat objects. They have been categorised under an internal standardisation system called "NBD standards".

Recently a programme has been finished in which nine systems of various manufacturers have been tested. There are ongoing discussions with the manufacturers, especially with respect to some of the performance tests required in the selection procedure. Eventually the manufactures will be responsible for generating and submitting the data in conformance with the selection procedure.

Step 4: Selecting a system by comparing functional requirements and functional properties

As stated before the degree to which the properties match the requirements determines the selection of a protective system. In case of a situation which, as far as functional requirements are concerned, is within the "standard" one of the approved systems from the relevant categories may be used. The selection is a more or less straightforward affair. In case of deviations and incomplete data the evaluation of the subsequent risk is carried out on a project level in close conjunction with the regional offices.

TESTS AND TEST PROCEDURES

The current accelerated weathering tests used in the selection procedure are as follows:

- TNO corrosion cabinet;
- Weather-O-Meter (WOM) test;
- Saltwater spray test ASTM B 117;
- Fresh water immersion test IS0 2812-2;
- Saltwater immersion test ISO 2812-1.

The tests are designed in such a way that the two main deteriorating mechanisms, namely deterioration of mechanical properties and corrosion, are tested. The TNO corrosion test is a cyclic corrosion test and the only test so far that uses artificial rainwater with a combined SO_2/CO_2 exposure.

The WOM test is used to artificially age coating systems by utilising artificial sunlight (Xenon) with frequent and significant changes in temperature. The test panels for the WOM test have a number of "V" shaped grooves that simulate an in- and outward edge in the substrate at which concentrations of internal mechanical stress in the coating system may develop, ultimately resulting in cracking of the system. The WOM test is not used as an attempt to try and create an artificial environment which accurately represents the actual environment but to measure the development of specific properties of a coating film during the ageing process. Important properties that are determined before and during the WOM test are loss of mass and volume, elasticity, tensile strength, elongation at break, etc. Each individual property or more likely a combination of altering properties may result in cracking of the coating film.

Test programmes

Since 1994 five test programmes have been completed in order to be able to select coating systems for the repair of specific coating problems on the Eastern Scheldt barrier, the Maeslant barrier and the Haringvliet barrier. In 2001 a general programme was initiated to test systems of various manufacturers several systems according to the three different standards of functional requirements. There are plans to initiate an additional programme before the end of this year.

Experience with test programmes

In contradiction to conventional (standardised tests) the test programmes have proven that the tests used are reliable in reproducing actual defects on a laboratory scale. By exposing the relevant coating systems to the present WOM cycle the problems with the cracking of coating systems on various projects such as the Eastern Scheldt barrier were reproduced. (see also figure 1 and 2)

Based upon the measurement of specific properties at intervals during the test the responsible mechanisms could be traced. Also the reference system that has been tested in all the programmes until now has shown a constant performance which proves the consistence of the test methods

Compared with conventional (standardised) test methods the Rijkswaterstaat test procedure has proven to be adequately discriminating for coating systems for infra structural works. As an example of this in table 1 two glass flake epoxy systems are compared. These systems were generically identical but were supplied by two different coating manufacturers. The performance nonetheless differs considerable in some aspects of the test.

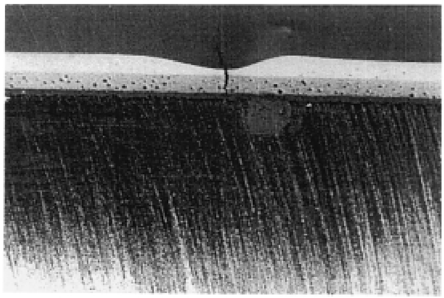


Figure 1. crack at depression in film as a result of concentrated internal stress

Figure 2. surface cracking of coating

System A has failed in practice on a flood barrier. After two years of exposure unacceptable cracking developed. Both systems meet the same generic description stated in part 5 “Protective coating systems” of ISO 12944. When tested in accordance with the procedure under part 6 of ISO 12944 both systems would have been considered suitable.

Table 1

	System A		**System B**	
	Before exposure 1500 hrs WOM	After exposure 1500 hrs WOM	Before exposure 1500 hrs WOM	After exposure 1500 hrs WOM
E-Modulus KN/mm²	0,980	2,904	2.144	2.021
Shrinkage %	-	2,5	-	0,3
Tensile strength in Mpa	16.1	36	31.1	27

Discussions with manufacturers

A number of accelerated weathering tests, some of them standardised such as ISO 12944 and ISO 20340-A, are being used at the moment. Manufacturers have in the past suggested alternatives for the Rijkswaterstaat tests in the selection procedure. After careful evaluation by a national panel of coating experts it was concluded that these alternatives are less suitable for Rijkswaterstaat. A rather large difference exists between the number of test cycles in the selection procedure compared with other cyclic tests. The WOM test is the only test which utilizes a Xenon gas discharge lamp. The light spectrum of the lamp comes closest to natural sunlight.

Systems that have failed the test programme and have also failed in practice will easily meet the requirements of ISO 12944 part 6. Considering this, as well as the substantial financial risks in case of premature failure of a coating system in relation to the costs of testing as such, the present test methods will be adhered to until alternative procedures have proven to be suitable. This suitability will not only be a matter of comparing the working principle of different test methods but will be decided by the extend to which alternative tests are able to generate comparable data with respect to the functional requirements. Alternative programmes could be validated by exposing coating systems that have already (preferable more than once) been tested in the present procedure to alternative tests and compare the data.

REFERENCES

Relevant references are considered the most important aspect in the selection of coating systems. During the most recent test programme manufacturers were asked to supply information with respect to projects were the system to be tested has already been successfully used. The amount of relevant results that have been received has however been somewhat disappointing. The supplied data is often insufficiently detailed and no more then a list of objects supposedly coated with the system at some point in the past. The current status of the system is not known nor is there information about the composition of the system (film thickness, number of coats, etc.) in relation to the system to be tested. Not all objects are readily available for inspection. Considering the importance of practical experience in the selection of a system this should be improved.

FINGERPRINTING

Since the performance of a coating system in practice or in a test is directly related to the composition of the individual products fingerprinting was introduced to guard against unnoticed or unannounced changes in the composition of products. Other end users as well as a number of manufacturers have recognised the importance of fingerprinting. Fingerprinting is also included in ISO 20340.

A fingerprint involves an Infra red and XRF analysis as well as the assessment of a number of basic properties such as mass, solids by volume and viscosity.

The purpose of the fingerprint is not to fully identify the products as such but to obtain general data with respect to the generic composition. This data can at a later stage be used to verify the composition of products to be used on an actual project.

Given the complex nature of the analysis and composition of some coating products the interpretation of comparative results can not be outlined in absolute grades or percentages but should be left to experts. It is important that the technical perimeters of the fingerprint are defined clearly to avoid misinterpretation. It is also important that, when using the fingerprint as a quality control tool during an actual coating job, a procedure is drawn up clearly outlining the sequence of actions to be taken as well as the responsibilities of all parties concerned.

SUMMARY AND CONCLUSIONS

Rijkswaterstaat has developed and used the selection procedure for coating systems since 1994. The procedure consists of four steps.

- Object data is translated into functional requirements for the coating system.
- The functional requirements include test data but also practical performance, environmental aspects and application properties.
- The functional properties are compared with properties of possibly suitable systems.
- Based upon the extend to which the properties match up with the functional requirements a selection is made.
- The object properties and functional requirements have been summarised in standards for three specific object categories.

The selection procedure has proven to be useful for Rijkswaterstaat in selecting coating systems for on infra structural works. The Dutch Directorate-General for Public Works and Water Management has no intention of permanently committing itself to the use of the present test methods. The test methods that have been adopted in the selection procedure have however proven to be reliable in reproducing actual defects on a laboratory scale and provide adequate and accurate information with respect to the functional requirements. The objects that, until now, have been coated with systems selected with the selection procedure have performed satisfactory. Systems that have been selected with the procedure to replace or repair those that have developed cracking have until now not shown any new problems. In view of this the selection procedure will remain in function.

At the present time more and more alternative tests and test procedures become available, most of them derived from ISO 12944. These will be studied closely and compared with the currently used methods on the level of functional requirements.

Rijkswaterstaat is already actively involved in the search for alternative test methods and will remain to do so in the future. The initiative should however be taken by the coating industry.

FUTURE

Outdoor exposure test

During the most recent test programme additional test panels for outdoor exposure have been prepared. These will be exposed to atmospheric and/or immersion conditions for a period of at least five years. The purpose of this is not to add another test to the programme but to validate the exposure of the lab tests. The change in properties of the exposed systems such as elasticity, corrosion from a scribe, tensile strength, etc. will be measured once a year. A visual assessment of the panels will be performed twice a year. By comparing this data with the data obtained during the lab testing a comparison can be made between the rate and nature of weathering in the lab test and actual outdoor exposure. This information will be used in the future development of the selection procedure.

Fingerprints

Recently there have been some discussion and misunderstanding about the way fingerprinting of products should be handled on project level. A Fingerprint procedure will therefore be developed that can be used as an integral part of a specification. This procedure should clearly state all the technical as well as procedural aspects of fingerprint identification.

Project references

Considering the importance of references in the selection of coating systems the possibility of generating a data system for references will be investigated. This system will be fed by inspection data generated by or under supervision of Rijkswaterstaat. Its purpose is to serve as feedback for assessment of coating system performance but more importantly for the future design of structures.

Modelling

Rijkswaterstaat demonstrated that the risk for unexpected and unacceptable failure of coating systems can be significantly reduced by introducing a selecting method based on functional requirements. However, this method is still largely based on exposure tests. The main general known disadvantages of testing is that it takes (to much) time. Predicting the actual service life solely based on tests is, despite the reliability of the Rijkswaterstaat procedure, almost impossible.
At this moment Rijkswaterstaat is supporting the start of a new development to simulate the behaviour of a coating system by using a computer model. This could offer many advantages in

drawing up more reliable maintenance strategies. The same model could, in theory, be used by coating manufacturers for the development of new products.

Integral life cycle

Considering the fact that most of Rijkswaterstaat objects are designed for a service life of 100 to 200 years there is a strong demand for drawing up reliable protection strategies. The service life of an organic protective coating system such as considered in this paper performs an average service life of 25 years.

Based on this fact new strategies for maintenance of large infra structures are developed in The Netherlands. Key feature in this new strategy is development of long term (100 years) programs. The complete life cycle from "cradle to grave" is considered. Integral Life Cycle Thinking is strongly related to drawing up functional requirements. In providing a durable protection of an infra structure not only traditional organic coatings will be selected. Alternative non coating solutions such as spray applied metals may prove to be a suitable solution for specific problem areas of a structure.

In designing new constructions considerations with respect to accessibility for coating, preventing the influence of micro climates at specific details and the selection of materials not requiring coatings are to be made as well.

Reference:

By Jan Bijen and Jo van Montfort, "Cracking of High-Solids epoxy coatings on Steel Structures in the Netherlands", Materials Performance vol. 38, no. 5, May 1999

Appendix:

Functional requirements and tests for selection procedure