Improved Service Life Prediction and Test Capability for Wood Coatings
The EU ‘SERVOWOOD’ Project

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Abstract:

SERVOWOOD is an EU funded project whose goal is to develop and establish European Standards that will facilitate the prediction of service life for exterior wood coatings across different climatic zones, and to significantly improve the capability of short term laboratory tests, including accelerated ‘weathering’, to predict behaviour under field conditions. The total budgeted cost of the project is €3.8m. It is supported by a consortium of 15 partners including representatives from the coating and joinery industries, and five major European Research Institutes. A key strategic element of the project is to develop models that will provide a causal link between the input dosage (e.g. irradiance, wetness temperature), and the coating system response of critical performance metrics for both laboratory and field based exposure. The project started in January 2014; this paper will review the background to service life prediction for wood coatings and outline the planned work programme.

Introduction:

Materials of construction undergo progressive changes during their working environment which are of a chemical and physical nature. Sooner or later a point is reached where functionality is compromised and remedial or preventative action is required. This represents an ‘end of life’ condition which in engineering terms may also be described as a ‘limit state’. It is seldom clearly defined and this represents one of the many difficulties in measuring service life. Another complicating factor arises from the fact that materials are used in structures containing a multiplicity of elements which may have different failure rates with the possibility of interactions. At present the service life performance of coating systems intended for exterior conditions can be assessed in two principal ways:

- Natural Weathering
- Accelerated “weathering”

Natural weathering, either in-situ or through controlled field exposures, causes substantial delays in the commercial exploitation of new formulations since real-time data is required. A minimum of twelve to twenty four months data is usually required to begin to make an estimate of service life. However coated products such as window frames may be guaranteed for much longer periods and early performance is not a sure indicator of longevity. The consequence of this is to cause delays in the launch of new products, or the launch of untried products that may have reduced durability and lifetime. This poses a substantial threat to both the reputation and brand of any coating manufacturer and to any external wood construction product manufacturer with the threat that the entire sector’s reputation is eroded thereby leading to replacement by alternative materials such as uPVC. Accelerated weathering yields guideline qualitative information, but at present cannot be relied upon for predicting real life durability. There is also the issue that the relative performance, including the rank-order of coating systems varies according to the climatic conditions and the nature of the substrate.

Weathering exposure tests may be preceded, or supplemented by various shorter term physical measurements which can aid the R&D process and improve the likelihood of success in the field. Examples include:

- Mechanical Properties (Extension to break; Elastic Modulus)
- Adhesive performance under wet conditions
- Liquid and vapour water permeability
- UV Transmittance

For each case it is usually possible to establish values which are necessary but not always sufficient for good performance. In the absence of a well-defined dose-response model validation through weathering tests is still required. Moreover the initial physical properties are themselves subject to ageing and dosage effects and must also be subject to exposure testing.
Therefore, there exists a need for the further development of methods that will lead to

- Standard methods of known precision to predict the service life of a wood coating using an accelerated test regime
- A means to predict service life from one set of climatic conditions to another

This would substantially improve the rate and quality of new coating formulation development and enable wood component manufacturers to confidently select the best coating for durability in their circumstances. Any new initiative should clearly build upon the substantial amount of work already carried out, some of which is reviewed below.

**Project Objectives**

The strategic objective of the SERVOWOOD project is to develop and establish European Standards that will facilitate the prediction of service life for exterior wood coatings across different climatic zones, and to significantly improve the capability of short term laboratory tests, including “accelerated weathering” to predict behaviour under field conditions. Advances made in service life prediction (SLP) in other fields lend strong credibility to the feasibility of this objective and will also contribute to knowledge about the mechanisms through which coated wood degrades. As a substrate wood presents specific coating problems that arise from the nature of the wood species and the interaction with the coating system. Countries within Europe have different sources of timber including species from both soft and hardwoods. The influence on performance will be addressed by the project and enable SME’s to have a wider choice of wood species which will in turn facilitate the use of wood as a sustainable resource. Better prediction and quantification of Service Life will facilitate ‘Cradle to Grave’ measures of sustainability in contrast to ‘Cradle to Gate’ assessments that create potential bias towards inferior products. SME Associations will play the key role in coordinating the needs of the supply chain sectors and in the dissemination and exploitation of the results.

**Current State of the Art**

Within the Coatings Industry durability has been defined as:-

- The period of exterior exposure during which the coating will retain an acceptable appearance, protect the substrate and not require any maintenance other than cleaning.
- The degree to which coating systems withstand the destructive effects of weather.
- The capability to reliably perform an intended function over a long service life under reasonable conditions of use.

Service life is often defined as a time period before replacement or repair (maintenance) is required; thus for many purposes Durability and Service Life are equivalent.

The literature relating to service life and its related elements is considerable and in the USA an initiative led by Martin et al (NIST- National Institute of Standards & Technology), led to a series of symposia dedicated to SLP and its ramifications. These conference reports represent a comprehensive overview of the state of the art in S-L-P, and the issues and problems to be resolved many of which relate to coated wood as well as other substrates.

The importance of wood as a material in construction, and the problems of protection have attracted considerable attention in European Research including COST Actions. For example the main objective of COST Action E18 was to improve the performance, durability and environmental properties of coated wood structures and products. Significant advances in understanding were made and reported at several conferences including the 4th International Woodcoatings Congress held on 25-27 October 2004 in The Hague. In April 2011 a new Action ‘COST FP1006’ was initiated to build on this work and increase understanding of the effects of modifying the surface of wood. Papers concerning durability
and service life have featured in all of the nine International Woodcoatings’ Congresses – of which this is the latest.

For the past 20 years the European Standards Committee CEN TC139/WG2\(^7\) has met several times a year to develop test methods and performance specifications for exterior wood coatings\(^8\). A number of test methods have been developed including artificial (EN927-6) and natural (EN927-3) weathering. However it has not been possible to find the resource to address the problems of service life prediction, and the alignment of laboratory and field-based exposure that are the subjects of this project. The consortium includes many of the scientists who have participated in both past and present COST Actions and are also members of CEN/TC139/WG2 and is thus ideally placed to build on past experiences.

Predicting service life presents both strategic and tactical options. At the top level there are broad choices. For example should data be acquired from real time exposure in the expected service environment, or should it be generated in a more controlled ‘artificial’ and usually accelerating environment? If the latter approach is chosen then many tactical choices will be presented in terms of apparatus and measuring techniques. Another strategic decision concerns the metrics that will be used to quantify the progression of change. In the case of coatings these might include properties of direct interest to the user such as simple loss of gloss. Alternatively a more fundamental underlying property such as modulus of elasticity can be monitored or at deeper level some aspect of chemical degradation. The choice made will have particular implications for the interpretation of the data and the type of model that might be used for prediction. There are also strategic choices between methodologies that influence both the design of the experiments and the tools of analysis. Martin\(^9\) and others have drawn a distinction between ‘Descriptive’, ‘Scientific’ and ‘Reliability’ methodologies. A key element of SLP is to define a time to failure by identifying various ‘limit states’ which trigger action, such as need for maintenance. Limit states may be phenomenological as in a loss of gloss, or based on underlying technical changes such as Tg (glass transition temperature), or the disappearance of a specific absorption band. There is also an issue that the ‘time to failure’ of replicates and real structures will show a very wide and non-normal distribution. Some elements in a study may not reach the limit state, these are commonly described as ‘censored’ but must be dealt with in the analysis.

\textit{Table 1} summarises how SERVOWOOD will deal with a number of SLP issues.

<table>
<thead>
<tr>
<th>SLP Problems</th>
<th>SERVOWOOD Solutions</th>
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<tbody>
<tr>
<td>Practical coating failures invariably show a wide and often non-normal distribution.</td>
<td>Data analysis will be conducted to determine the underlying distribution.</td>
</tr>
<tr>
<td>Incidents of early failure may have more practical significance than average service life.</td>
<td>The Weibull distribution can accommodate early failure and ‘censored’ results.</td>
</tr>
<tr>
<td>Outdoor exposure conditions are not reproducible</td>
<td>Conditions will be treated as a variable</td>
</tr>
<tr>
<td>Quantification of exposure environments (natural or artificial) is poor.</td>
<td>Data-logging and monitoring facilities will be used</td>
</tr>
<tr>
<td>Durability data is multivariate</td>
<td>Both chemical and physical data will be collected and multivariate analysis deployed</td>
</tr>
<tr>
<td>There is no reason to expect direct correlation between different coating chemistries under different service conditions whether natural or artificial</td>
<td>No assumptions about correlation are made, and a separate external dosage model will be developed as a key deliverable.</td>
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For manufacturers, strategic decisions must also be based on an appreciation of the consequences of failure both in terms of reputation or specific warranty claims. These will differ significantly between for example a fence coating and a window frame coating. Decisions must also rest upon an expectation of a significant end-of-life indicator which might range between any change in appearance, or the deterioration of a protective function. Neither is likely to be unequivocal, like an electrical bulb failure, nor can it be assumed that there is a single failure mode. Some situations require prediction of isolated early failures (the ‘infant mortality’ phase in reliability theory) while in others information is needed about...
the long term gradual (wear-out) change that may ultimately require maintenance. Strategies of investigation are likely to differ between established products undergoing minor change as opposed to significant technology or formulation changes. In turn this leads to another strategic question, namely whether an absolute prediction of lifetime must be made, or whether it is sufficient that it should be relative to that of another known composition. Testing against a Weathering Reference Material (WRM) is a common practice in the industry in development work but leads to little insight about underlying factors. The European Standard methods use a reference material known as the ICP (Internal Comparison Product) which is well characterised but based on solventborne technology. Despite their usefulness the value of a WRM is undermined by the fact that the rank order of coating performance can change according to the substrate and exposure conditions.

All S-L-P methods require data, and in the case of exterior weathering this may be a major factor in the product development cycle. One way of generating the necessary data is to have an extensive outdoor exposure program preferably under service conditions. This is expensive and does not give fast feedback, particularly for new technologies and where the desired lifetime is a long one. Thus to meet the objective of shortening development cycles other approaches are used such as:-

- Artificial accelerated weathering
- Intensified natural weathering
- Extrapolation from early results
- Mechanistic studies

All these approaches require some kind of quantified interpretation; hence statistics and model building have an important role to play. In general however, although the coating industry uses all of these methods there is a great deal of truth in the assertion that the industry and its customers are wary of laboratory based tests. Natural weathering is preferred, with its attendant disadvantages of poor repeatability and reproducibility as well as long leads times. This is in marked contrast with electronics, aeronautical and medical industries, and indeed it is hard to see how these latter industries could have grown so fast without considerable reliance on predictive laboratory testing.

Some views about laboratory testing are summarised in the following quotations. Wicks¹⁰ asks “Is the use of accelerated weathering devices better than nothing?” and reaches the conclusion “Probably not!”, while Martin and co-workers¹¹ have asserted “Attempts at refining the current durability methodology have been made over the last 80 years without any significant improvement in its predictive capability”. Many similar observations can be found in the literature.

The current methodology referred to in this case is the practice of correlation between small sets of exterior exposure panels with laboratory-based experiments (artificial weathering) and the assumption of similar rankings in other environments. The difficulty of establish any correlation between (and within) ‘real world’ and accelerating techniques is well illustrated by a ten year study initiated by an ASTM task force¹². A wide and representative selection (23 technology and colour variants) of coil coatings was exposed in Florida and Phoenix, and also subjected to both intensified natural weathering and a selection of standard accelerated weathering cycles. None of the accelerating methods gave acceptable correlation (which was taken as a Spearman Rank Correlation Coefficient rho value = 0.9 or better. Correlation coefficients were also determined for the 10 year natural weathering results in comparison with 7, 5, 3 and 2 year data. For gloss loss there was a reasonable correlation between the 10 and 7 year results but not with the earlier periods implying that final performance could not necessarily be inferred from early performance. The final conclusion from this very large piece of work was that “No accelerated technique was able to suitably correlate with real-time weathering”. Moreover it can be seen that correlation was not particularly good within the natural weathering series showing that rank reversals were taking place even during the course of weathering.
Figure 1: SERVOWOOD represents a paradigm shift from forced correlation to a scientific dosage model

The situation seems even worse when natural weathering result from different sites is compared since there is the inescapable fact that both weather and climate show substantial variations between and within exposure locations. Hence a first challenge is to explain why natural weathering conditions must be described by terms such as ‘mild’, ‘medium’ and ‘severe’ (e.g. in EN 927-1). Car manufacturers have long appreciated that some climatic regions are more severe than others, and will insist on exposure in specific climates, such as Florida, for qualifying specifications. It is also the case that the rank order of coating performance will vary between sites, thus there is no possibility of a simple correlation of coating performance between weathering sites, or within the same site at different periods. Logically therefore, before addressing artificial accelerating methods, it is necessary to quantify the degrading factors for natural weathering (including at least solar radiation, temperature and time of wetness) using appropriate metrics, and then relate their effects to the response characteristics of specific polymers and formulations. It is from this standpoint that a dosage based model requires laboratory and field testing to be accorded the same status from the point of view of model validation, even though the objective is to predict behaviour under natural exposure conditions. Thus a successful methodology should be able to explain differences in service life between different climates and at different times, as well as the performance under controlled and possibly accelerating laboratory conditions. There should be a seamless join between the means used to interpret laboratory and exterior exposures including the damage and exposure metrics. Furthermore the model should be able to explain how other factors will affect the dose/response relationship including for example angle of exposure, degree of shelter, substrate and formulation factors.

The SERVOWOOD project will address the problem of rank order reversals and lack of correlation between sites and between weathering devices by establishing the dose-response relationship with a scientific model. Lack of correlation must not be seen as ‘wrong’ but rather as the true consequence of dose-response relationships when one of the factors is changed or intensified. The conventional approach to weathering assumes a constant acceleration rate for all materials tested whereas a dosage model would account for different rates of change according to the natures of the material and hence be able to explain and normalise rank reversals. This would represent a major advance in understanding and enable greater confidence in service life prediction.

The present state of the art is represented by natural weathering of small panels on various weathering sites over a period of years, supplemented by short more intensive exposure in weathering devices, but with serious reservations about correlation. To gain the several benefits offered by improved service life prediction will require a dosage/response model which can be applied equally to laboratory and field based exposure. Ideally this should be deterministic in nature in order to understand underlying mechanisms of degradation in physical or chemical terms. Achieving this is contingent on methods of characterising both the dosage and the response, collecting and analysing a lot of data and selecting the best type of model. Much of the work that has been published relates to metal substrates; the SERVOWOOD project will address the special attributes of wood that modify the response of the coated substrate to environmental challenge. Thus the following issues are being addressed:
Characterisation of dosage factors by methods which are equivalent for laboratory and field exposure

Variation of one or more dosage factors in a systematic manner for both laboratory and field exposure

An experimental plan with experimental designs that aid data analysis at a realistic level of experimentation

Quantification of coating system degradation (damage) by methods which are repeatable and reproducible

Selection of the most appropriate methods for analysing and modelling the data

Validation of model capability against real world experience

Dosage Factors

Coated wood in service is subject to many challenges including hail and biological attack which are difficult to accelerate. For the purposes of the project the main emphasis is on the role of solar radiation moderated by water and temperature effects.

Photo-degradation

There is an underlying assumption in much accelerated testing that raising the level of a ‘stress’ such as UV radiation will simply increase the rate at which changes occur such that the damage depends on the total absorbed energy, and is therefore independent of radiant intensity and exposure time. This is known as a reciprocity law. However there are exceptions to this simple assumption. At various radiant flux thresholds different reciprocity relationships have been observed, indicating that alternative, system dependent degradation paths have been followed. Reciprocity coefficients will be determined for the coating polymers used in the project.

It is often the case that the damaging effects on natural weather are caused by the combination of solar radiation and wetness from rain and dew. Models, which take these factors into account as damage indices, have shown improved predictive power. However determining the role of water on wood coating durability is complex (see below) and presents a major problem in aligning laboratory and field testing.

The simulation of solar radiation for laboratory experiments is particularly problematical and has been much studied by specialist companies. Among the issues to be addressed are:

- The light source (e.g. xenon arc, halide lamps, filters)
- Relevance of Wavelength to specific problems and environments
- Spatial Uniformity in test chamber
- Radiation Intensity
- Spectral Power distribution of source

Although the solar flux generated by the sun is effectively constant, the amount reaching any terrestrial object will be modified by angle of incidence and distance travelled through the atmosphere. During passage, absorption and scattering processes from air, ozone and other gases, water vapour will modify it leading to altitude and local differences. The angle of incidence of sunlight may be calculated by taking into account factors which include latitude and the slope of the exposed surface. Graphical representations of the angle of incidence have been published, which will also vary as a function of latitude. Because the influence of incident angle on irradiation will be modified by atmospheric conditions dosage is normally measured rather than calculated at reference weathering sites. The variability in solar dose as a function of angle offers a means to investigate this parameter as a variable. In much weathering the angle of exposure is fixed and this limits the information of the dose/response relationship.
A surface exposed to the sun will receive maximum radiation at the time when the angle of the sun’s rays is normal (90°) to the surface. For a fixed surface during the day the intensity will be distributed around a maximum according to the time of day and latitude. In the northern hemisphere fixed test panels are usually faced south at a specific angle. Maximum radiant energy will be received at the ‘latitude angle’, e.g. 25° for southern Florida, 33° for Phoenix, Arizona, 51° for London. By convention many coatings are tested at 45° which is considered a good compromise and more severe than a vertical exposure. A fixed 5° angle is more severe in summer months than 45° and will also collect more dew and rainfall; however 45° would receive more solar energy in the winter months. Compared to vertical exposure, 45° has a significant accelerating effect and for wood coatings has been shown to range between factors of 1.5 to 2.0 depending on the composition. This will reflect time of wetness differences, as well as irradiance. The solar radiation (and temperature) can be further increased in various ways that include backed mountings, focussing mirrors and continual or continuous variation of the exposure angle (e.g. EMMAqua® and Q-Trac®). A wide gamut of test configurations is thus available with options of spraying with water.

Devices such as EMMAqua, Q-Trace and others are expensive to construct and while they may intensify weathering factors they do not provide the systematic variation that would provide the basis of a dosage model. As an alternative the SERVOWOOD project is designing a relatively inexpensive multi-faceted construction that will enable the simultaneous exposure of coated sections to natural sunlight but with the dosage modified by the angle of exposure and the option of varying temperature and time of wetness. This approach will have limited accelerating capability but will provide a dose/response relationship from a single exposure apparatus, and will also be relevant to the different degradation aspects that arise from the orientation aspects of a building. Exposing several such apparatuses around Europe will create a database for model validation. Designing a test rig is not a trivial task. The current European natural weathering test (EN 927-3) took over ten years to refine and validate a single wooden test piece due to issues of repeatability and reproducibility against the background of weather variability.

Time of Wetness (TOW)

Water is a major contributor to coating degradation, with specific effects according to the nature of the substrate, wood is prone to movement and decay. Apart from substrate-water interactions, coatings exposed externally are subject to hydrolysis causing scission, while photolysis leads to free radical photo-oxidation, further exacerbated by the presence of water. Water is also a carrier for other materials and may contain salt or acidic materials. In consequence exterior-weathering investigations will usually record rainfall data. It is now recognised that this is not sufficient as a dosage factor, since dew formation may account for more water on a surface than rainfall. Moreover the nature of the specimen, including its insulation value and residual heat content will markedly influence the TOW. Although rising temperatures e.g. of a panel as sunshine increase, will evaporate water it may also increase water absorption. Differences in TOW between laboratory and field exposures are a thus potential source of poor agreement between laboratory and field exposures, and may be difficult to manage even in controlled experiments. Using load cells, Boisseau et al recorded ~250 litre water on a 24 cm² panel in 56 days. In contrast 300 hours of the SAE J1960/J2527 cycle, (approximately equivalent to three months outdoor weathering in irradiance terms) used only 24 litres of water.

Furthermore the water in ‘weatherometers’ is usually deionised and not necessarily representative of rain and dew. TOW varies greatly and is greatly influenced by the design of test panels on weathering sites. Backed panels undergoing radiative cooling, i.e. at nightfall, do not gain heat from ambient air as fast as un-backed panels and will fall below the dew point for longer periods, thus remaining wetter. Clearly the angle of exposure will affect water run-off; at low angles 0°-5°, water will collect in droplets, this is very noticeable when water repellents are present, as is common with exterior wood finishes. The combined effect of high UV and long TOW leads to a faster rate of photo-hydrolysis and may be sometimes seen on the flat surface of wooden balustrades. Decreasing the angle of exposure also affects mould growth.
TOW is thus useful as a means of accelerating or maximizing a particular mode of service life degradation, and if varied systematically can be used to investigate dosage relationships. Fischer and Ketola investigated TOW as a water-stress multiplier by comparing a range of materials exposed at Phoenix, Miami, and St. Paul (MN), In most cases failure was faster in the wet environment (typically 12%) with some materials showing a greater sensitivity (68% faster). TOW is likely to interact with other dosage factors and but may also be confounded with UV and temperature effects.

Temperature

Although the UV portion of sunlight is very damaging to polymers it accounts for only 5% of the total energy; around 51% is radiated in the infrared range. Not surprisingly this has a major effect on the temperature of exposed coating. White paints reflect a large proportion of infrared radiation, but much more is absorbed by darker colours including black; dark coloured paints can consequently become up to 30° hotter than pale ones, unless the latter contain infrared reflecting pigments. The actual temperature of a coated coloured surface will depend on the angle of exposure modified by other factors such as the specific heat and mass of the coated substrate as well as insulation and ventilation (wind speed). Ideally the temperature of an exposed coating in service should be measured using data logging and appropriate sensors but models have also been developed to predict temperature based on heat and radiative transfer mechanisms. The influence of temperature can be addressed through relationships such as the Arrhenius equation. This equation predicts a doubling of reaction rate with a 10° rise in temperature, and this is often the case with chemical reactions. However weathering degradation which is subject to light and moisture stress, will follow more complex kinetics. One study showed an average acceleration factor of 1.41 (SD 0.23) for a 10° C temperature increase, the maximum recorded was 1.89. Although this is less than the doubling predicted by Arrhenius it still represents a significant increase.

Temperature is thus an important element of any accelerated testing study for both natural and laboratory weathering and is the subject of field and laboratory investigation during the SERVOWOOD project.

Interaction Factors (Influence of substrate and coating formulation).

A serious problem with much published analysis of the effect of weather on coating degradation is to measure the average ambient conditions and treat this as ‘the dose’. The SERVOWOOD project will address this problem by concentrating on the effective, rather than the applied, exposure dosage. Thus for example panel temperature rather than ambient temperature must be used when modelling. However there is still scope for further modulation of the dose through attributes off the coated substrate, for example water permeability or interfacial properties. There is therefore an additional task within the project to explore how various coating/substrate interactions will further modulate the applied dose (radiation, temperature, time of wetness) and translate them into the effective dose that must be used in the model.

Model Development

The development of mathematical models to account for the relationship between effective dosage, add the subsequent response, for both natural and accelerating conditions is a key challenge for the SERVOWOOD project. The scientific literature shows many different types of model which will range from empirical to fully mechanistic. Both types can be seen as deterministic or stochastic (containing random elements). It has been said that ‘all models are wrong – but some are useful’, and the value of models will be evaluated against their usefulness according to the criteria set down by SME’s and other users. This will of course include the capability to predict service life in the real world from accelerating regimes, but also to account for differences between climatic zones.
The model definition depends upon the assumptions made and the extent to which actual physical or chemical processes are described. Within the model some consideration must be given to how the distribution of the predicted service life will depend upon the external factors. Distributions may be normal but others including lognormal and exponential may be used, including the Weibull\textsuperscript{25} distribution. Three common generic models used in accelerated failure testing and service life prediction are Arrhenius, Eyring and Inverse Power Law. Arrhenius, familiar to chemists, describes the temperature dependence of some feature of the distribution to a rate equation. Activation energy can be estimated graphically from plots of tests carried out at different temperatures. Temperature is expected to have an accelerating effect on chemical reactions and as already noted an effect on exposure degradation. Arrhenius models are often linked with the Weibull distribution. Work by Schutyser and Perera\textsuperscript{26} illustrates an application of the technique. Good agreement was found for a high Tg coating. The significance of Tg is noteworthy for different mechanisms might operate above and below the Tg. The temperature range over which the experiments are carried out should not enter regions of unknown reaction mechanism and this is a general caveat for any model with a temperature term. The role of Tg has already been studied by some partners and will be included in the project.

A disadvantage of the Arrhenius model is that it only includes one stress term whereas the Eyring model can contain two terms, one of which is temperature. In contrast to the empirical Arrhenius equation Eyring’s model is theoretical and based on statistical thermodynamics. It might therefore be used to combine temperature and humidity effects. Selection of the best predictive model may be an iterative process but guided by knowledge of the physics or chemistry of failure. Under some circumstance it may be also appropriate to transform the data that will be inputted into the model and more accurately describe the failure mechanism. Transforms are used for mathematical reasons but might also be used to make the variable more meaningful e.g. as a scaling factor related to customers expectation of service life.

The combination of a distribution function with a model containing physical elements has been illustrated in some other studies\textsuperscript{27,28}. The physical elements to be incorporated into a cumulative damage model must link with the investigative techniques. Thus gloss loss might be linked with surface roughness. Changes in surface energy can be related to contact angle changes\textsuperscript{29}.

**Time series analysis**

This is a technique for making forecasts from data that are a sequence of measurements over a period of time. It is widely used in business forecasting and inasmuch as weathering is a time series process, a number of authors have drawn attention to the potential value of this technique. An essential element of normal regression analysis is the assumption that measurements carried out at different times are independent. This is clearly not the case in much coating degradation (e.g. gloss loss) where the next result clearly depends to a large degree on the previous one and the order of observation must be taken into account. The residual errors in a time series are correlated, and this provides a mathematical tool to investigate the data. There are a number of time series techniques such as the ‘ARIMA’ approach (Autoregressive Integrated Moving Average) of which the ‘Box and Jenkins’ variant is one of the better known\textsuperscript{30}. Whether or not an ARIMA model is appropriate will depend on the nature of the data.

**The Work Program**

The SERVOOD project started in January 2014 and is divided into a number of work packages which are linked to provide the information flows necessary to meet the project’s objectives (Figure 2). An essential activity is to record the dosage (irradiance, wetness and temperature) and transform this into an actual dose which reflects the response of the coated substrate. Thus darker colours will have a higher temperature and shorter time of wetness than lighter ones; polymers will have different UV absorption according to their chemical structure etc.; all factors to be taken into account in the model development. Another important requirement in developing predictive models is to be able to systematically change the variables and use experimental design techniques to analyse dosage-
response relationships. The present European accelerated weathering test was developed following the ARWOOD project (reported at the 3rd PRA Woodcoating Congress); the cycle comprises 24 hours of condensation followed by a sub-cycle of 2.5 hours of UVA-340nm and 0.5 hours of water spray. At the time a number of different cycles were compared but it was not possible to systematically study all the variables, it is now recognized that the period of exposure is much drier than that normally encountered in natural weathering. In fact there is a more general recognition that accelerated weathering protocols "do not allow sufficient time during their nominal wet cycles for paint systems to become saturated". During the project further investigation of the cycle will take place with a particular aim to increase the time of wetness. On the face of it systematic variation of natural weathering is less easy to achieve; however it is possible to moderate the impact of natural weathering by altering the angle of exposure and increasing both temperature and wetness of the exposed test panels. The project is therefore building multi-faceted exposure racks with provision for internal heating and external water spray. PRA has previously had some success in altering the temperature and wetness for coil coatings exposed at 45 degrees.

Figure 2 SERVOWOOD – Work Package Relationships

The experimental work that will provide the data for the modelling work has been divided into four phases.
• Phase 1: The formulations include the current ICP (WRM) in pigmented, un-pigmented, waterborne and solvent borne variants.

• Phase 2: Solvent and Waterborne formulations are selected on the basis of mechanical and permeability properties that are known to give a difference in performance.

• Phase 3: Here the variable is the influence of the substrate and includes hard and softwood cut with either zero or ninety degree grain angle.

• Phase 4: The detail of phase 4 is not finalized as it will depend partly on feedback from the earlier phases but will include formulations which are known to show characteristic types of failure.

An important supplementary objective for Phase 1 is to prepare a precision statement for EN 927-6 covering both repeatability and reproducibility.

The experimental designs for these phases all include film thickness as one of the variables. It is generally well known that thicker coatings have a longer service life than those with a low film thickness. (See also Gruell et al35) This is because the total coating thickness will affect many aspects that contribute to service life including effective elastic modulus, adherence, UV screening, temperature, diffusion rates of moisture and oxygen. Therefore with proper experimental design the effect that film thickness has on durability might be separated into the contributory factors that are affecting service life.

Conclusion

Despite the very large number of publications on weathering, durability and service life their still remains a tendency for workers to look for a correlation between artificial and natural weather, and to seek to adjust variable parameters to improve the correlation. The SERVOWOOD project offers a means through modelling to explain the dose/response relationship independently and to therefore interpret reasons for correlation or lack of it. It is likely that the model would require a calibration step in which case artificial weathering would have a role in calibrating coating response to dosage factors which can then translate to a service life prediction under different condition.

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7 CEN TC139/WG2 Exterior Systems for Wood, Mission: Coating systems for the protection and decoration of wood used in buildings, classification, test methods and performance specifications.
Wood coatings to artificial weathering using fluorescent UV lamps and water. By a probability density function, such as the normal distribution. The Weibull distribution is particularly flexible and often used in reliability work.

Though the numerical value given to the outcome of an experiment may be discrete or continuous, the latter described by a probability density function, such as the normal distribution. The Weibull distribution is particularly flexible and often used in reliability work.


BS EN 927-6:2006 Paints and varnishes. Coating materials and coating systems for exterior wood. Exposure of wood coatings to artificial weathering using fluorescent UV lamps and water.

Podgorski et al. ‘A reliable artificial weathering test for wood coatings.’ Coatings World, February 2003 pp39

