AMOG Consulting · Bureau Veritas · University of Reading · The University of Newcastle Australia

Seawater Corrosion Of Rope & CHain (SCORCH)

1. Objectives & Scope of Work

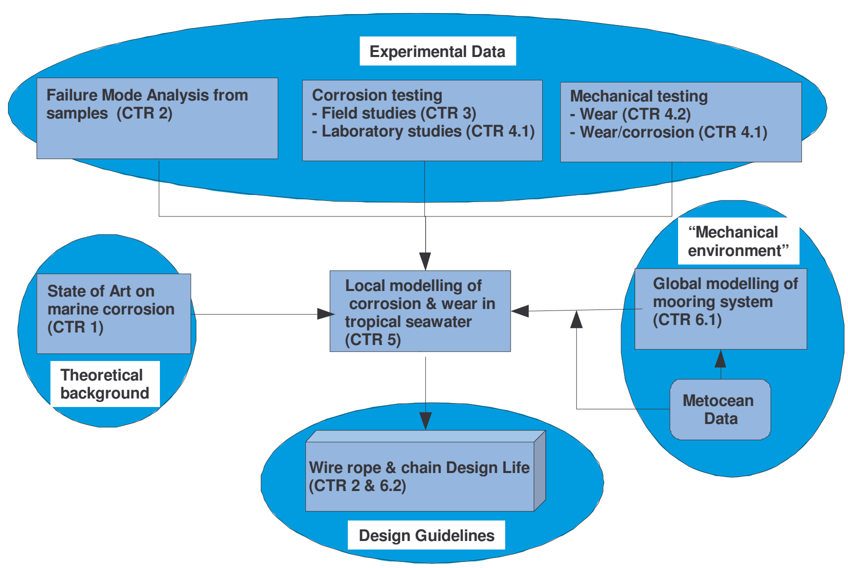
Existing guidelines (API, BV, DNV and ISO) for estimating wire rope and chain corrosion have been derived from measurement in cold waters. No guidance on the effects of seawater temperature on the life of the materials used to construct offshore moorings is available, despite temperature being a major factor on rate of corrosion and thus the life of such materials. The lack of accuracy of existing design rules is an acknowledged issue within the industry. Design guidance suitable for the prediction of life of mooring materials in ocean conditions of various temperatures is required to improve their reliability.

The objectives of the SCORCH JIP are to provide participants with:

- Design guidance on the specification of wire ropes and chains to maximise their design service life for given site conditions, in particular in tropical waters.
- Design analytical tools, underpinned by field and test data, to estimate the design service life of steel wire mooring ropes and chains for given input site conditions.

The overall program of the SCORCH JIP will include the following tasks:

1. Conduct a state of the art literature review on corrosion in seawater.
2. Acquire and analyse material samples.
3. Conduct field studies to quantify the effects of the marine environment on service life.
4. Conduct laboratory studies to quantify the effects of the marine environment on service life.
5. Conduct data analysis and modeling.
6. Develop design guidance.



2. Failure Mode Analysis from Samples

This task of the SCORCH JIP will involve wire rope world expert R.C. Chaplin. Used mooring rope specimens from across a broad range of operational circumstances will be gathered and examined in detail in order to increase the "sample space" of empirical data on zinc dissolution rates under various operational conditions. The objective of this task is to gather real world samples of mooring materials and from these to better describe the effect of local conditions on the failure mode and rates of failure of these materials. A number of potential SCORCH JIP participants have already agreed to provide samples of wire rope.

Outer strand (above) and IWRC (below) from 6-strand upper segment of mooring rope with A-gal outer wires, **after 13 years deployment in North Sea**.

Corroded and fractured outer A gal. wires of 6-strand catenary line from Kumul SPM recovered **after 4.5 years in tropical water**.

3. Field Studies

This task of the SCORCH JIP will involve corrosion world expert RE Melchers. A series of field tests on wires, wires ropes and chains samples will be conducted to quantify the effects of external factors driving corrosion in marine environments, including:

a. Effect of temperature will be analysed by testing samples at three locations:
   - 13°C averaged in the Tasmania site,
   - 17°C averaged in the Newcastle site,
   - 28°C averaged in the Townsville site.

b. Effect of flow velocity will be studied at Swansea Channel (Newcastle, NSW), at three different sites along the channel.

c. Effect of oxygenation will be investigated though splash zone exposure, using tidal rigs.

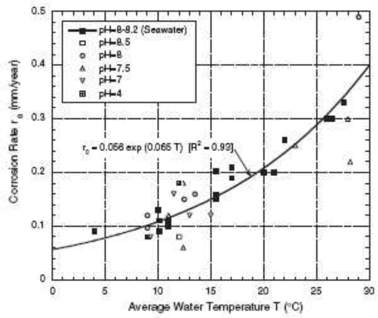
d. Effect of marine growth.

e. Effect of possible cathodic protection will be investigated by including damaged wire in immersion and tidal samples.

4. Laboratory Studies of Corrosion/Wear

4.1 Corrosion testing

This task of the SCORCH JIP will involve the performance of an extensive set of controlled laboratory trials at Newcastle Australia, in a laboratory operated by Prof. Melchers. Natural in-situ sea water is used in this experimental facility. Existing test rigs and similar new ones will be used.



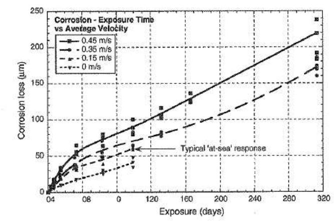


Fig. 5. Effect of water velocity on early corrosion loss.

Table [5]: Laboratory Test Matrix (minimum)

Specimen Type	(a) Temperature	(b) Flow Velocity	(c) Oxygenation	(d) Marine Growth & SRB	(e) Cathodic Reaction	Total
Wires	2S, 4R	2S, 4R, 2V	2S, 4R, 2DO	2S, 4R	2S, 4R	56
Ropes	2S, 4R	2S, 4R, 2V	2S, 4R, 2DO	2S, 4R	2S, 4R	56
Chains	2S, 4R	2S, 4R, 2V	2S, 4R, 2DO	2S, 4R	2S, 4R	56
Total	**24**	**48**	**48**	**24**	**24**	**168**

Note: S = Number of Repeat Samples, R = Number of Recoveries of samples during exposure trials
X = Corrosion endurance parameter subject to investigation and quantification

For field and laboratory studies, water quality will be monitored during the test, including measurements of temperature, salinity, pH, pollution (iron chromatograph), nutrients and suspended solids. The experiments will be performed on both the individual components (the wire and chain links) and the complex mechanical system (the wire rope and the chain).

The Field and Laboratory Tests will involve:

- Mass loss examinations.
- Pit measurements.
- Microscope observations.
- Analyses of rusts including:
  - Scanning Electron Microscopy (SEM) to reveal surface details that cannot be resolved by light microscopy.
  - Energy dispersive X-ray analysis (EDS) to identify the elemental composition.
  - X-Ray Diffraction (XRD) to investigate the structure of crystalline materials, from atomic arrangement to crystallite size and imperfections.

4.2 Mechanical testing

Corrosion and wear are the two main degradation mechanisms affecting chains and wire ropes. These two mechanisms may interact together as wear will remove the protective layer, therefore increasing corrosion rate, and corrosion will affect the material internal composition and therefore its mechanical properties and ability to resist wear. This task of the SCORCH JIP will:

- Test the accuracy of existing wear models in the literature by means of laboratory experiments.
- Measure the breaking load limit of the samples to exhibit the relationship with corrosion level.

5. Data Analysis and Numerical Modeling

Accelerated corrosion of zinc coated wire rope has been extensively studied by Chaplin and Potts. These studies included a recent survey of samples of broken wire ropes in tropical waters and the generation of a global model for the corrosion of zinc coated wire rope. Accelerated corrosion of steel due to temperature, flow velocity and microbiological activity has been extensively studied by Melchers et al. over the last 7 years and corrosion models are now available to account for the effect of external parameters such as temperature, oxygen content, biological activity.
The experimental results will be used to calibrate numerical models to explicitly predict the expected lifetime of wire ropes and chains in tropical waters:

- A numerical tool will be developed to model corrosion endurance of steel wire ropes of typical constructions under a range of different operational exposure conditions including temperature, flow velocity, dissolved oxygen level and zone location (splash zone, mid-catenary, low-catenary or ground).

- A numerical tool will be developed to predict the expected lifetime of chain link subject to wear and corrosion. In the offshore industry, it is generally assumed that chains are exposed to continued high rates of corrosion, in part due to the working of the chain not permitting a build up of protective rusts. The experimental results will allow validation (or not) of such an assumption and the development of a model for estimating the corrosion loss of low-alloy steel chain under continued immersion corrosion conditions. Chain corrosion outside of the contact area will also be investigated. The procedures will include the effects of water temperature, salinity, water velocity, and surface roughness on steel corrosion under field conditions.

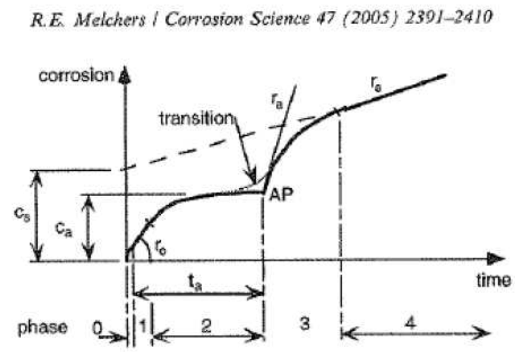
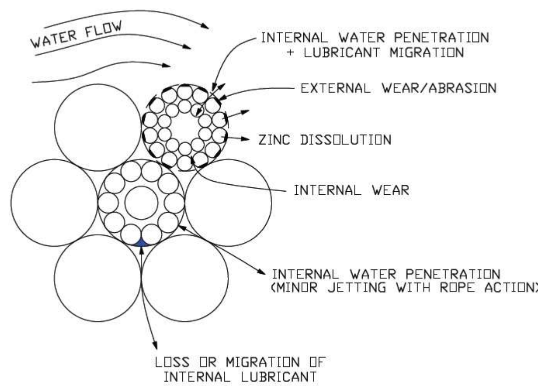


Table [3]: Physical And Mathematical Description Of Each Phase And Of Its Evolution With Temperature.

Phase	Phase description and corrosion controlling mechanism	Governing parameter as a function of T	Correlation coefficient
0	Short-term initial corrosion governed mainly by chemical kinetics	-	
1	Approximately linear function governed by oxygen diffusion from surrounding water without inhibition from corrosion product and marine growth	$r_0=0.076\ exp(-0.054T)$	$R=0.963$
2	Non-linear function governed by oxygen diffusion through corrosion product layer of increasing thickness	$t_a=6.61\ exp(-0.088T)$ $c_a=0.32\ exp(-0.038T)$	$R=0.99$ $R=0.94$
3	Anaerobic bacterial corrosion phase governed by transport and diffusion of energy source stored in corrosion product to corroding interface	$r_a=0.066\ exp(0.061T)$	$R=0.97$
4	Approximately linear long-term anaerobic bacterial corrosion phase.	$c_g=0.075+5678T^{4}$ $r_g=0.045\ exp(0.017T)$	- $R=0.71$

Notes: reproduced from Melchers.



6. Design Guidance

This task of the SCORCH JIP will focus on data analysis and modelling of the corrosion and corrosion/wear processes for wire rope and chains as a function of environmental exposure and working conditions. These models will be reviewed by Bureau Veritas with the aim of deriving both recommendations and application guidance that will be fit for class rules and other industry codes of practice (e.g. API RP 2SK).

7. Key Personnel / Contacts

The present scope of work will be conducted by world experts, including Prof. R.C. Chaplin for wire ropes and Prof. R.E. Melchers in the fields of corrosion and reliability, together with highly recognized personnel from AMOG Consulting and Bureau Veritas. A full prospectus is available on request. Estimated total budget is AU$ 750k (approx. EU 400k). Estimated completion time is 2.5 years.

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