# Developing Guidance for Designing with High Strength Cupronickel Alloys: Microstructural, Geometrical and Environmental Requirements for Reliable Service

**RESEARCH PROGRAMME CONCEPT**

**PROP303103**


## Summary

High strength cupronickel alloys are commonly used in the oil and gas industry where a combination of high strength, anti-galling properties and, resistance to corrosion and hydrogen embrittlement are required. Applications include many high value parts of critical subsea infrastructure including locking probes and other complex fastening systems. Despite their excellent properties, and significant alloy development, high strength cupronickel alloys are not impervious to environmentally-induced cracking with several unexplained and high-cost failures reported by various operators over recent years.

The circumstances and mechanism(s) of failure vary, in each case, but stress corrosion cracking (SCC) and hydrogen embrittlement (HE) have been reported as the active cracking mechanisms. The root cause of these failures has not been fully established, because of unique circumstances of failure in each case, which include a variety of environments, complex loading conditions and cathodic protection schemes, and the difficulties associated with replicating the observed failure mechanisms in controlled laboratory environments.

The logic of this research project is to carry out a detailed assessment programme, studying the effects of relevant environments on high strength cupronickel alloys, in order to identify the critical parameters causing cracking in service. The goal is (i) to prevent future failures by refining the material specification, in an analogous manner to that that which has been achieved in API 6CRA, for other alloys, and (ii) to establish quantitative critical design parameters, such as maximum design loading and environmental limits, applicable for the safe operation of high strength cupronickel components in subsea service.



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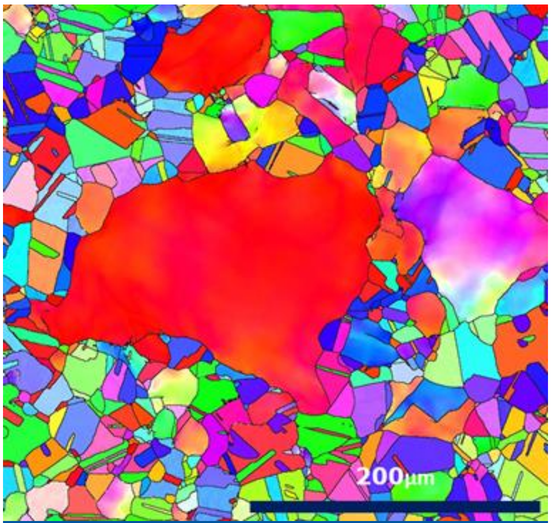
## Project Concept

### Cupronickel components

High strength cupronickels are often used in complex fastening systems, joining high value components of subsea infrastructure, for which a combination of high strength and corrosion resistance is required. The complex nature of these assemblies also means that the high strength cupronickel components are exposed to cathodic protection systems, which generate hydrogen, making resistance to hydrogen embrittlement another critical material property. In addition to these demanding requirements, cupronickel components, such as locking probes, are often deliberately designed with sharp notches and/or threaded sections to enable installation and emergency disconnection of critical components. These features add to the demands placed on the material by adding complex stress concentrations into the component design.

All of these complexities contribute to difficulties in successfully identifying the root cause in cases in which components fail. Recent failures have occurred unpredictably and have been attributed to a range of factors which are often unique to the failed component.




EBSD map showing a bimodal grainsize distribution in a cupronickel alloy.

### Factors contributing to failure

- **Production route:** It is known that thermo-mechanical processes are the chief determining factors in the final properties of the component, in these particular alloy systems; however, the relationship between processing and environmental performance is not understood. Often 'equivalent' materials from different suppliers have been found to have different grain sizes and grain size distributions. Varied precipitate distributions have also been identified along grain boundaries in some, but not all, reported failures.
- **Environment:** Failures have occurred in a variety of environments, most subsea, with factors including interaction with mercury (from natural gas), hydrogen sulphide (derived from the degradation of grease) and amine containing environments (resulting from epoxy paints and lubricants) all cited as potential causes of failure. However, clear and reproducible root causes of failure are very often difficult to establish. Moreover, most subsea failures have been associated with some degree of cathodic protection; however, the extent of hydrogen uptake and its reported significance in each failure is unknown.
- **Applied load and stress concentration:** The majority of reported failures occur at stress concentrating features such as notches and threads and the local microstructures neighbouring those regions. However, the influence of these features on initiating failure has not been established and it is not known if failures could have been avoided with design changes, such as using less sharp notches and/or more conservative safety factors in component design.

### Proposed solution

Despite the complex range of contributing factors, there are some common features amongst failures, in particular, the fracture surface morphology has a brittle intergranular nature. This has led to SCC and HE being proposed as the primary cracking mechanisms, in most cases. Some susceptibility to these cracking mechanisms has been reported in high strength cupronickel alloys and so it is not possible, currently, to design against such failure mechanisms, with confidence.

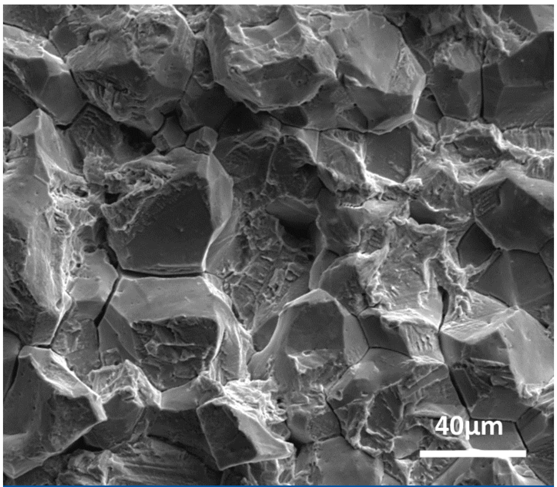
The proposed project will undertake a large testing programme to evaluate and compare the performance of high strength cupronickel alloys for a range of environments, test temperatures, loading regimes and microstructural conditions in order to:

- Characterise the microstructure systematically and quantitatively;
- Reproduce the fracture morphologies observed in service failures;
- Identify the critical factors controlling susceptibility of high strength cupronickel alloys to failure by SCC and HE.

## Objectives

The project will evaluate the environmental performance of high strength cupronickel alloys in relevant subsea environments aiming to:

- Identify the primary factor(s) leading to failure of subsea cupronickel components;
- Tighten the specifications for high strength cupronickel materials, analogous to what has been done in the API 6A CRA Standard;
- Establish design parameters to facilitate operation of safe and reliable cupronickel components by design.




SEM fractograph showing intergranular cracking morphology in a cupronickel alloy.

## Benefits

Sponsors of this project will benefit from:

- Development of microstructural and design specifications to enable design against environmental failure of high strength cupronickel systems;
- Reduced likelihood of failure in the field and hence, reduced associated costs:
- More informed material choice to prevent environmentally-assisted cracking of high strength cupronickel alloys in subsea environments;
- Access to a suite of verified environmental test data comparing performance of high strength cupronickel alloys with respect to environments, material tempers and test conditions;

## Approach

### State of the art

High strength cupronickel alloys have undergone a significant amount of development, leading to the evolution of various grades, including Hiduron 130, Hiduron 191, Marinel and Nibron Special, which are currently available for subsea service. All of these alloys are based on the precipitation strengthened Cu-Ni-Al system, with controlled additions of Fe and Mn to optimise the materials for strength, toughness and resistance to SCC. The history surrounding the development of these alloys is complex and not well known, so the project will start by conducting a state-of-the-art literature review, identifying the rationale behind the development of the alloys and collating all relevant environmental testing data. The results of this survey will be used to define the microstructural environmental testing programme.

### Environmental Testing

The environmental testing programme will consist of two phases:

**Phase 1: Reproducing fracture surface morphologies consistent with reported failures**

The initial goal of the environmental test programme will be to reproduce observed failures, enabling a detailed study of the most influential parameters. The results of the literature survey will be used to identify relevant environments which are likely to cause embrittlement and/or SCC of the selected cupronickel alloys. Three types of mechanical testing could be used to evaluate performance; slow strain rate tests (SSRTs), incremental step loading (ISL) and constant load (CL) tests. The test programme will be developed to include an assessment of the three types of testing to identify the most appropriate test method for reproducing the observed failures. The influence of other test variables including: strain rate or applied load as applicable, the need for hydrogen pre-charging, the potential of the applied cathodic protection and test temperatures amongst other parameters will also be considered.

**Phase 2: Evaluating the significance of microstructures, environment, stress concentrations, temper and alloy chemistry on performance**

Having established a method to reproduce observed failures, the aim of the project will turn to establishing the relative influence of environment, stress concentrations, material temper and alloy chemistry on the susceptibility of high strength cupronickel alloys to the identified failure mechanism. Selected alloys will be tested to compare performances of each material in the test developed in Phase 1. The aim will be to identify the material most resistant to embrittlement and/or SCC in the selected test environment. Notched test specimens and/or materials with different thermomechanical histories may also be tested to evaluate the influence of these factors on performance, as necessary. All test specimens will be subject to detailed fractography and microstructure characterisation using light and scanning electron microscopy to correlate microstructural features to the observed embrittled material.

### Development of material and design criteria

In the final part of the project, the results of the environmental testing, fractography and microstructural characterisation will be linked to identify the most critical factors causing embrittlement of high strength cupronickel alloys. Where possible, these factors will be distilled into design criteria, defining parameters such as, maximum stresses/strains and limiting stress concentrations to be used in component design. It is also hoped that the results will be used to develop a material Standard, analogous to API 6A CRA, to define the required specifications in terms of microstructural condition and mechanical properties required to optimise resistance to embrittlement and safe application of such alloy systems as a result.

## Deliverables

- State-of-the-art review summarising the environmental performance of high strength cupronickel alloys;
- High quality material data measuring their environmental performance in oil & gas applications;
- Defining the attributes of high strength cupronickels and design guidelines for components which will minimise their susceptibility to embrittlement.

## Further Information

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