REVIEW OF AVAILABLE MATERIAL ON USABILITY AND SUITABILITY OF HIGH STRENGTH
MOORING CHAIN

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ABSTRACT

In recent years several incidents related to failures of high strength
mooring chains used in mobile offshore units mooring systems have
been reported.

Investigations of some of these incidents have been carried out by, or
on behalf of, the chain owner, the rig owner or the operator involved,
resulting in a set of explanations for why they occurred. As a result, a
set of possible measures to counteract them have been launched.

In this paper a systematic review of the available data is made and
discussed, and some conclusions on the possible root causes and failure
mechanism for the failures are presented. A gap analysis on the specific
material knowledge was performed and the resulting suggested research
and test program is presented.

KEY WORDS: High strength; mooring chain; hydrogen sensitivity;
HISC; failure; brittle fracture.

NOMENCLATURE

<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AHV</td>
<td>Anchor handling vessel</td>
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<tr>
<td>CP</td>
<td>Cathodic protection</td>
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<td>CTOD</td>
<td>Crack tip opening displacement</td>
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<td>FOW</td>
<td>Floating offshore wind</td>
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<td>FOWT</td>
<td>Floating offshore wind turbines</td>
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<td>GOMO</td>
<td>Guidelines for Offshore Marine Operations</td>
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<td>HSE</td>
<td>Health and Safety Executive in the UK</td>
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<td>ICCP</td>
<td>Impressed current cathodic protection</td>
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<td>HISC</td>
<td>Hydrogen induced stress cracking</td>
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<td>HV</td>
<td>Vickers hardness</td>
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<td>HS</td>
<td>Significant wave height</td>
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<td>KIEAC</td>
<td>Environment assisted cracking stress intensity</td>
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<td>MBL</td>
<td>Minimum break load</td>
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<td>MOU</td>
<td>Mobile offshore unit</td>
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<td>NCS</td>
<td>Norwegian Continental Shelf</td>
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<td>RS</td>
<td>Mooring chain material grade per DNV-OS-E302</td>
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<td>SACP</td>
<td>Sacrificial anode cathodic protection</td>
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<td>SEM</td>
<td>Scanning electron microscope</td>
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<td>SSRT</td>
<td>Slow strain rate testing</td>
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INTRODUCTION

Higher strength material mooring chains have become widespread for
offshore mobile units mooring systems on the Norwegian Continental
Shelf (NCS) and are expected to be essential for the viability of
Floating Offshore Wind Turbine (FOWT) installations. The high failure
rate observed in some productions of R5 grade material has resulted in
dedicated investigations and actions across the industry (Barros et al.,
2022).

The failures considered in this paper occurred in chain which were fully
compliant with the existing standards. It is observed however, that an
apparent heightened sensitivity to hydrogen cracking which associated
with surface damages caused by handling of the chain onshore and
offshore, in combination with high load events and CP exposure, has
resulted in the reported failures. Mitigation actions have been
implemented mainly focusing on reducing damages from handling and
high load events, but a more refined and clear criteria to properly
certify high strength material mooring chains needs to be established.

A research and testing program is proposed and described with the aim
of confirming the identified root causes and failure mechanism and to
provide quantitative background for the mitigation actions
implemented.

MATERIALS AND METHODS

The information presented in this paper has been obtained from the
available failure investigation reports, bibliographic review,
presentations at seminars, workshops and interviews with different
industry players. Chain manufacturers, chain rental companies, anchor
handling operators, rig owners and license owners have been consulted.

FAILURE INVESTIGATIONS SUMMARY

A total of 18 failures on R5 grade mooring chains have been noted to
have occurred between 2015 and 2022. Out of these 18 failures, only 13
material failure investigation reports were used in this study, due to
lack of complete information on the remaining 5 cases.

A summary of the failure conditions, failure reports and special
investigations performed is presented in the following sections.