Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 00 (2018) 000–000

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

14th Global Congress on Manufacturing and Management (GCMM-2018)

High Tensile Stainless Steel as a Sustainable Material for Aquaculture

Paul Gümpel[a], Arnulf Hörtnagl[b], Matthias Sorg[b]*

[a]*Konstanz University of Applied Sciences, Alfred-Wachtel-Strasse 8, 78462 Konstanz, Germany*
[b]*Institute for Materials Systems Technologies Thurgau, Konstanzerstasse. 19, 8274 Tägerwilen, Switzerland*

Abstract

The project aims for the development of a new material system from high tensile stainless steel wires as net material with environmentally compatible antifouling properties for off-shore fish farm cages. Therefore, current net materials from textiles (polyamide) shall be partially replaced by high strength stainless steel in order to have a more environmentally compatible system which meets the more severe mechanical loads (waves, storms, predators (sharks)). With a new antifouling strategy current issues like reduced ecological damage (e.g. due to copper disposal), lower maintenance costs (e.g. cleaning) and reduced durability shall be resolved.

Keywords: Stainless Steel; Aquaculture, Net System

1. Introduction

Aquacultures deal with the controlled growth of fish, muscles, crabs etc. Currently, about 150 fish species are farmed in Aquacultures (salmon, halibut, seabrass, tilapia, trout, carp etc.). Aquacultures are differentiated in fresh- and seawater-cultures. Seawater-cultures are known as “Mari-Cultures” and can be located both offshore (afloat) as

* Corresponding author. Tel.: +41-71-666-4204; fax: +41-71-666-4201.
E-mail address: guempel@htwg-konstanz.de

2351-9789

well as installed close to the coast which is the focused application in this project. Generally net cages consist of a frame construction to carry the net and the net itself. As a result of overfishing and increasing demand worldwide (increasing population etc.), aquacultures become more and more crucial in order to satisfy the worldwide needs. [1]

As a result of increasing needs and shrinking resources, aquaculture was gaining importance in the recent years. In the following years more than half of the fish consumed worldwide is going to be farmed in aquacultures. Due to high fish density in the farms and the resulting enhanced biofilm growth, the use of copper as antifouling (AF) strategy is a commonly occurring technique. Particularly regarding the increasing number of fish which will be produced in farms in the future, environmental friendly solutions are needed. Current trends focus on larger farms operated offshore. To make these farms working safe and economical, reliability has to be improved and maintenance costs need to be reduced. Also, alternative materials with higher mechanical strength, compared to current textile net materials, like common metal wires might be necessary for these developments. In the present work a new net system fabricated of high tensile stainless steel wires as net material with environmentally friendly AF-properties suitable for off-shore fish farm cages was developed. The challenge in this project was not only the material science related to production technology but also the system behavior of the material in regards to corrosion, bio-fouling and finally in developing an integrated anti fouling-strategy. [1,2]

2. Procedure in the project

2.1. Lab tests and immersion in natural environment

In a first step, the properties of various stainless steels were compared in order to meet both, the requirements in the production of nets and the requirements in the operation of the plants. Properties of different kinds of stainless steels were tested and evaluated. The requirement for high strength materials with sufficient residual deformability for the production of nets and the corresponding corrosion resistance for use in seawater can be best performed with the so-called corrosion-resistant duplex stainless steels (Fig. 1). They also offer the advantage of a high resistance to stress corrosion cracking in seawater. In the oil and gas industry, these steels have been used for many years in seawater with very good experiences. [3]

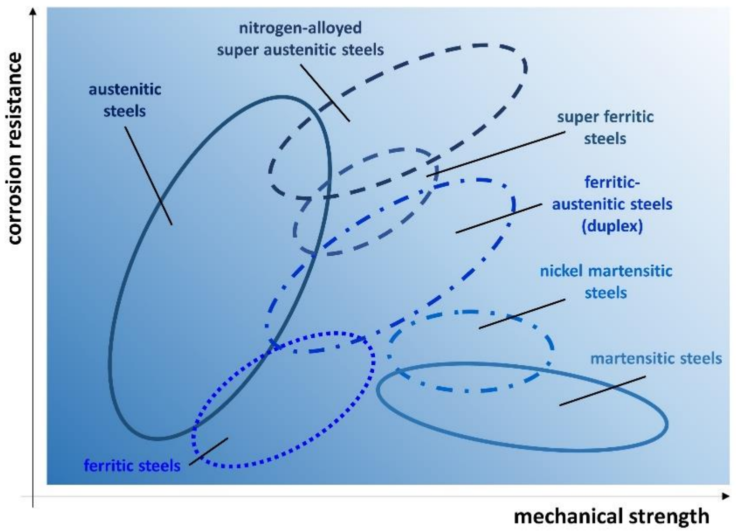

Fig. 1. Schematic overview - related corrosion resistance and strength of various steel variants

By using duplex stainless steels in cold worked condition all requirements regarding mechanical strength and corrosion resistance can be fulfilled. In laboratory investigations it could be shown that for the materials A (Alloy 2304 (1.4362)) as well as B (Alloy 2205 (1.4462)) the corrosion resistance in artificial seawater for the usual temperatures is given. However, the resistance of the molybdenum-containing material B (Alloy 2205 (1.4462)) is higher, which results in greater safety against additional load factors such as higher temperature, concentration of the chloride or biologically influenced effects on the corrosion process. In a highly specialized manufacturing process, nets were produced from these high-strength materials with a tensile strength up to 2000 MPa, which performs a much higher mechanical strength compared to current polyamide nets. [3,4]

A selection of different net systems (material and antifouling strategy) were exposed at eight sites worldwide (Fig. 2) for a period of minimum 6 months in order to investigate the individual fouling behavior compared to existing net systems in the practical use. Therefore, the samples were exposed in the area of fish farms or shellfish farms. The fouling was documented and evaluated in defined sequences using photography and light microscopy. Furthermore, the cleaning capability of different net systems was tested using a standardized cleaning process. After the immersion tests, the samples were evaluated concerning their corrosion and antifouling behavior. In addition to these immersion tests, laboratory tests were conducted, such as microbiological investigations and corrosion tests in order to investigate the different net systems and AF-strategies. [1, 5]

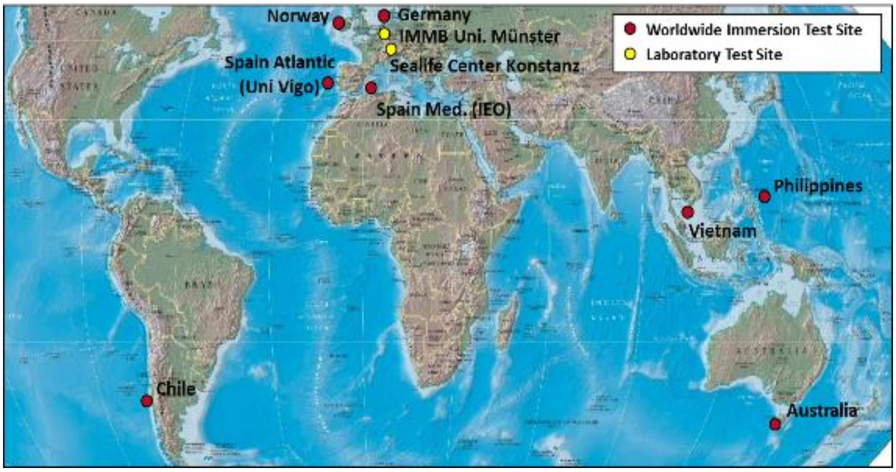

Fig. 2. Locations for Lab and exposition tests

2.2. Results

The results of the laboratory tests as well as the exposition experiments in different sea locations clearly showed that the evolution and also the growth of biofilms (Fig. 3) can only be sustainably reduced by the application of toxic substances, e.g. by Copper. In polymer nets, this is achieved by an infiltration of copper. Metal nets can be made from copper alloys or the surface of the steel is coated with a layer of copper or copper alloys. Surface coatings made of non-stick materials such as PTFE (polytetrafluorethylene) or nanostructured materials (shark skin effect) can reduce the biofouling compared to the pure steel surface, but fouling is only delayed but not prevented (Fig. 4).

During the exposition, cleaning tests were also done. The result can be described as follows: Steel / metal surfaces can be thoroughly and almost residue-free cleaned with a water jet. In the polymer nets, the cleaning result is significantly worse and biological studies have shown that there are significant residues of biofilm material in the network. Such residues of biological material accelerate re-biofouling.

The application of stainless steels with the much higher strength leads to thinner material webs and therefore a better surface ratio which results in much better water exchange in comparison to polymer nets. Regardless of the degree of biological growth, this will improve the living conditions of the fish. Through a continuous cleaning process, this positive state will lead to a higher sustainability. [5]

Fig. 3. Example for Biofouling at nets made of different materials

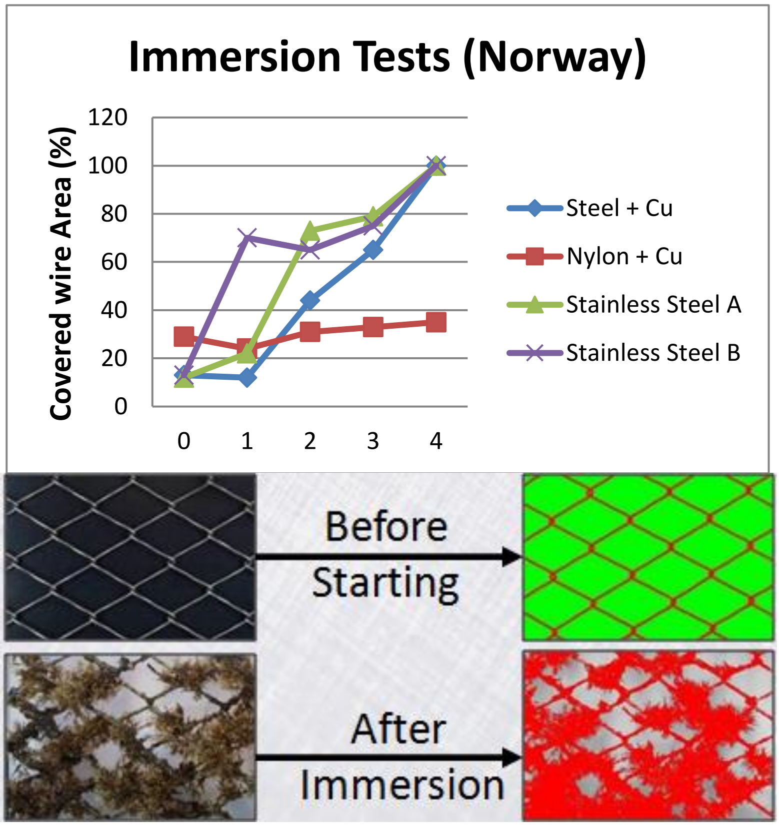

Fig. 4. Proportion of the covered area after long-term exposition in seawater (4 months)

2.3. Field experience

Due to the preliminary investigations, the strategy for the application of steel nets was established. These steel nets can be cleaned in an automated process with regular intervals by a water jet. For the first practical application the so-called Predatornets were selected. These somehow coarse-meshed nets keep predators such as seals away from the breeding/upbringing nets.

The first field experience took place in South America on the Pacific coast. Fig. 5 shows the supplied net rolls which were assembled on site to cages. Based on the results of the previous laboratory and exposition tests, the nets were made of the material A.

Surprisingly, after only a few months of real application in the Pacific Ocean corrosion attack took place mainly at the nodes of the mesh (Fig. 6). Some isolated corrosion attacks were caused by small, not visible defects in the surface. Generally the surface quality of the cold drawn wires in this high strengthened condition is a problem, these fabrication problems were solved by the steel supplier. [6]

The reason of the systematic failures in the node areas could be determined by failure analysis and simulating corrosion experiments. In field operation, there is severe friction at the node in the nets. This friction in the crevice under high mechanical load and seawater environment has led to tribocorrosion, in this special case the material was activated in the friction area and was not able to repassivate under these conditions. Simulation tests showed the activation. The OCP breaks down during friction load and increases when the friction stops (Fig. 7). A dependency on the time between the activation can also be seen. The investigations have shown very clearly that the material B has a much higher resistance with these test conditions than the material A (Fig. 8). With the material B, a temporary activation can occur, but a repassivation takes place quickly and securely. The stainless steel with the higher alloy content and therefore a higher pitting resistance value has a definitely higher tolerance against any type of corrosion.

Based on these experiences, some changes have been made. The most important change for the production of nets was the application of the more corrosion resistant material B. Furthermore, the structure and overall suspension of the cage has been designed to minimize friction in the nodes. After these changes, no systematic signs of corrosion were observed and the use of steel nets has been running mainly trouble-free for more than two years. The project is now in a phase where the long-term operation is observed and a continuous improvement process is carried out in real use. [5, 6]

Fig. 5. Installations in South America - Total 112’000 sqm

Fig. 6. Typical tribocorrosion in the friction area of a stainless steel net after some months in the Pacific Ocean

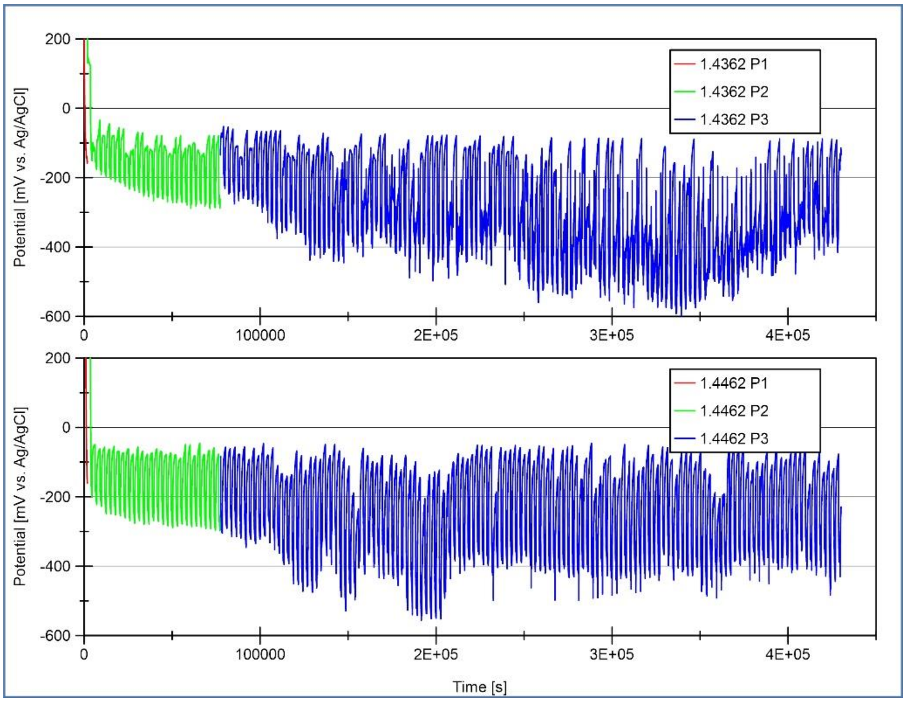

Fig. 7. Open circuit potential during friction simulation – peaks show repassivation when friction stops

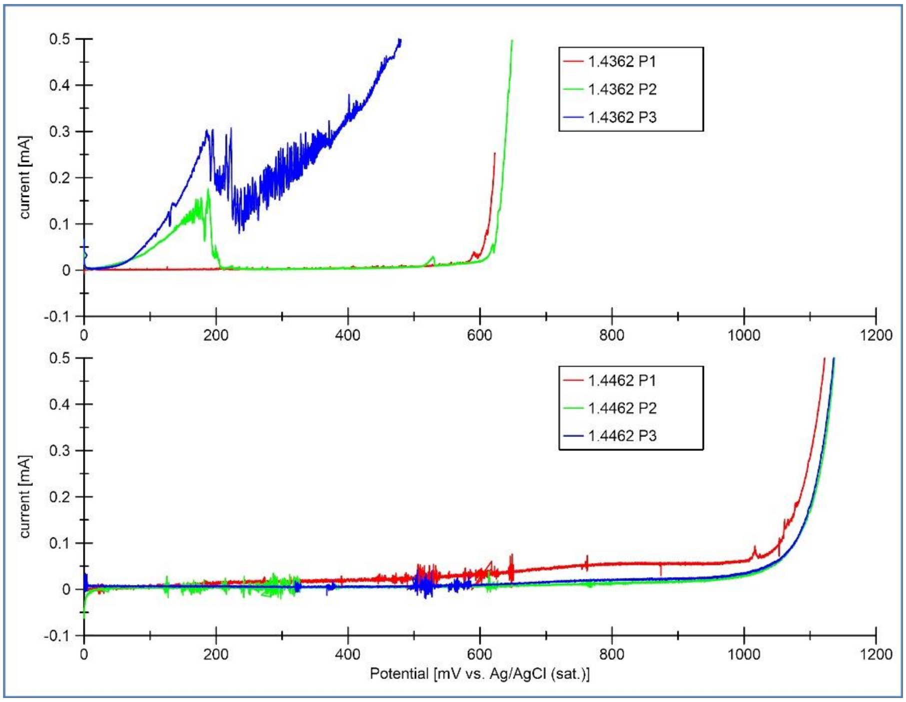

Fig. 8. Current-potential-curves after different times of friction simulation (see phases in Fig. 7.)

3. Conclusions

The performed tests revealed a much higher mechanical strength of the new high tensile stainless steel net system compared to current polymer nets. Even if the biofouling of the stainless steel net is slightly higher compared to current copper based solutions, a better cleaning capability could be observed. The material of the nets is 100% recyclable, no polymeres can waste the sea and no toxic material is used. The higher strength of the stainless steel enables a much smaller wire diameter of the net, which increases the level of water flow rate. This water flow is a very important parameter for the fish growth and their health. Cages made of stainless steel offer a trend for more sustainable fish farming

Acknowledgements

The project was funded under No 13398.1 by the Kommission für Technologie und Innovation. We thank the KTI for the financial and organizational support of this research project.

Sources

[1] Seemann, P.; Catch of the day; International Innovation, EuroFocus, 01/2013

[2] Seemann, P., Dornbierer, U., Sorg, M., Gümpel, P.: DEVELOPMENT OF A NEW MATERIAL SYSTEM FROM HIGH TENSILE STAINLESS STEEL WIRE WITH ENVIRONMENTALLY COMPATIBLE ANTIFOULING PROPERTIES FOR OFF-SHORE FISHFARMING CAGE; APA 2013 (Asian-Pacific Aquaculture), Ho Chi Minh City (VN), December 2013

[3] Gümpel, P.: Rostfreie Stähle – Grundwissen, Konstruktions- und Verarbeitungshinweise; 5th edition; Expert-Verlag; ISBN 978-3-8169-3148-5, 2015

[4] Huebner, U., Klöwer, J.; Nickel alloys and high-alloy special stainless steels – Properties-Manufactuering-Application; 3rd completely revised edition; Expert-Verlag; ISBN 3-8169-2195-7, 2003

[5] Sorg, M., Hörtnagl, A., Gümpel, P., Dornbierer, U.: Corrosion Effects on High Strength Duplex Stainless Steel Nets for Offshore Fish Farming, Proceedings of the EUROCORR 2017 & 20th ICC Congress, Prague, Czech Republic, 3rd – 7th September 2017, paper 86911,

[6] Sorg, M.,Seemann, P., Gümpel, P.: DEVELOPMENT OF A NEW CAGE SYSTEM FOR OFFSHORE FISHFARMING WITH ECOLOGICALLY FRIENDLY ANTIFOULING STRATEGIES, International Conference on Marine Corrosion and Fouling 2014 (Singapur)