Automated Underwater Arc Welding

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ABSTRACT

The Institut für Werkstoffkunde IW (materials science) of the Leibniz Universität Hannover investigates the influence of water depth on different stick electrode types for wet underwater shielded metal arc welding. To obtain reproducible welding conditions, a multi-axis welding machine is used inside a 30 bar pressure chamber. The environmental conditions such as temperature and salinity can be controlled while the water depth can be simulated by setting the internal pressure up to 30 bar, equivalent to 300 m water depth [1] [3].

1 INTRODUCTION

The enormous growth of the offshore wind power industry has increased the demand for the development and qualification of special underwater welding consumables for water depth higher than 20 meters. In order to understand problems associated with underwater wet welding and recommend possible solutions to the problems, the Institut für Werkstoffkunde applies an internal pressure chamber and a multi-axis welding machine for testing welding equipment. This welding compound offers excellent possibilities to investigate the welding equipment (power sources etc.) on one site and the welding process on the other. In recent studies the influences of different ingredients of the stick electrode coating have been investigated. Based on a typical rutile electrode composition the correlation of its amount into the covering and the welding properties in dependency of the water depth was investigated [5] [6]. Furthermore hydrophobizing measures to substitute the water-repellent coatings of stick electrodes have been investigated [2] [4].

2 EXPERIMENTAL EQUIPMENT

2.1 PRESSURE CHAMBER AND MULTI-AXIS WELDING MACHINE

The developed and constructed multi-axis welding machine is implemented in a hyperbaric chamber of 10 m³ volume, *Fig. 1*. Water depths from 0 to 300 m can be simulated in this chamber by filling it with water and generating equivalent pneumatic pressure. Also, tests in dry hyperbaric environment are possible.

Fig. 1 Hyperbaric welding chamber at IW

The multi-axis welding machine, shown in *Fig. 2*, consists of four modular parts:

- 3 - Axis portal (x, y and z linear axis)
- Rotation and tilt unit
- Welding unit
- Cleaning unit

An electrodes stack for dry storage of up to 100 stick electrodes enables continuous welding tests.

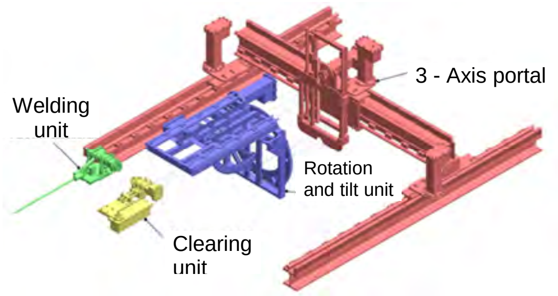

Fig. 2 Multi-axis welding machine components made from stainless steel

2.2 CONSTRUCTION OF THE GUIDE UNIT

The positioning device consists of 3 axes. Two guides are parallel to each other at a fixed distance in the X direction, a further axis in the Y direction perpendicular to those spans the working space. *Fig. 3* shows the arrangement of the axis directions to each other.

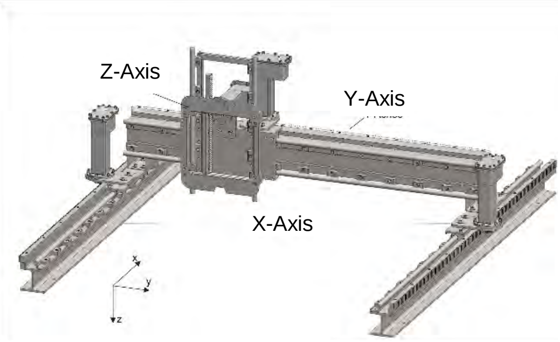

Fig. 3 Guide unit

The motion of the different axis is being realised by using electric step motors. To prevent leakage during the wet welding process under up to 30 bar, the electrical components have to be encapsulated from the surrounding medium. Housings against water penetration contain the entire engine-transmission combination, *Fig. 4.*

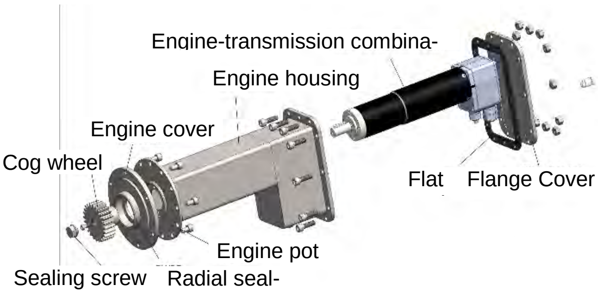

Fig. 4 Engine-transmission housing

Furthermore, the penetration of water is prevented by an over pressure balance between the housing and the surrounding water pressure. By simultaneous pressurization of the motor housing, while filling the chamber, the pressure difference between the components can be minimized. A slight overpressure of 0.1 bar in the housings further ensures that no moisture enters the housing. This pressure equalization principle applies to all electrical and pneumatic components.

The guides of the Y-axis are chosen to be identical to the X-axis. Because only one Y-axis is required, both of the guide rods are mounted on one side of the box profile. *Fig 5* illustrates the position of the components.

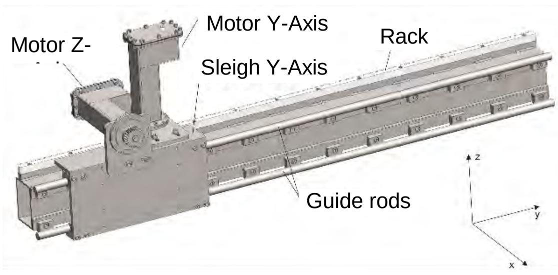

Fig. 5 Y-Axis and motor of Z-Axis

The Z-axis has been realized by a prepared welding frame structure of rectangular hollow sections. *Fig 6* shows the construction and the arrangement of the guide carriage in detail.

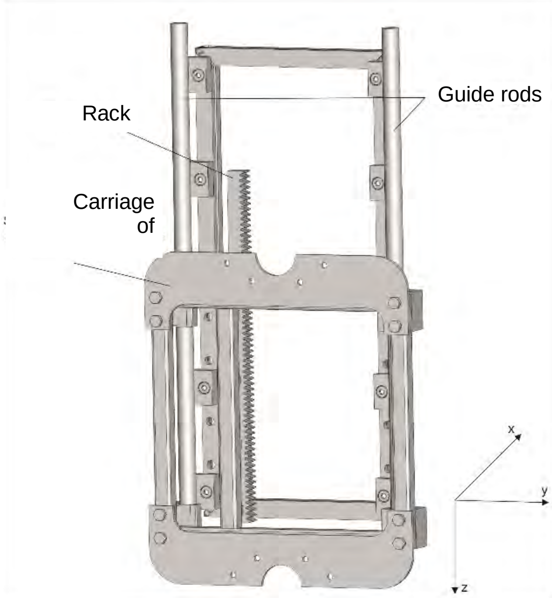

Fig. 6 Guide carriage of the Z-Axis

2.3 CONSTRUCTION OF THE WELDING UNIT

The construction of the equipment for automated welding with stick electrodes was based on the previous work at the IW. The automat consists of a linear guide, a driving unit, and the construction of an electro-pneumatic electrode clamp, *Fig.7*.

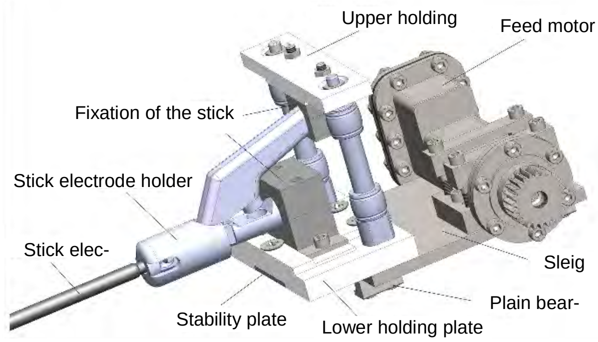

Fig. 7 Automat for welding of stick electrodes

The electrode holder is connected to an upper holding plate and a lower holding plate by pipe clips. To move the two plates towards each other, two pneumatic muscles are used. These pneumatic muscles also have to be pressurized with an overpressure during the filling of the chamber. The nominal operating pressure is 6 bar, resulting in a maximum internal pressure of the muscles of 36 bar.

In a PID controller, which controls ignition during the start of welding and the feeding rate of the stick electrode during the welding process, the control of the feeding process is guided by the arc voltage. If the actual welding voltage is higher than the predetermined volt-age, the stick electrode is fed faster towards the work-piece. In the case of a short-circuit or if the voltage is less than a predetermined voltage, the speed is reduced.

2.4 CONSTRUCTION OF THE CLEARING UNIT

In most cases, joining components under water needs multiple welding layers. This means that the individual weld layers must be cleaned before over-welding. For this purpose, a cleaning unit is designed to automatically remove the slag. The device consists of a linear feed axis, consisting of guide rails and drive motor, and a rotating brush, *Fig. 8.*

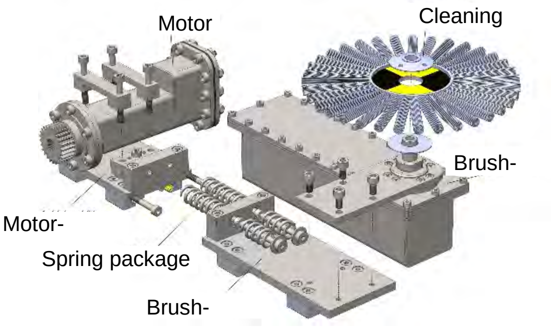

Fig. 8 Clearing unit

2.5 CONSTRUCTION OF THE ELECTRODE STACK

For an automatic use of the multi-axis welding system and reproducible welding results it is necessary to store stick electrodes within the pressure chamber. For that purpose a revolver magazine was developed. The electrode stack, containing a dry environment, provides 100 stick electrodes for fully automated operation of the multi-axis welding machine in the pressure chamber, *Fig 9*.

2.6 FUNCTION OF THE MULTI-AXIS WELDING MACHINE

The constructed welding equipment is suitable for single and multi-layer welding of fillet and butt welds. The joining of the components can be performed in all major welding positions. Furthermore, the plant is resistant to corrosion and can be operated completely submerged. The working area of the multi-axis welding system is shown in *Fig. 10.*

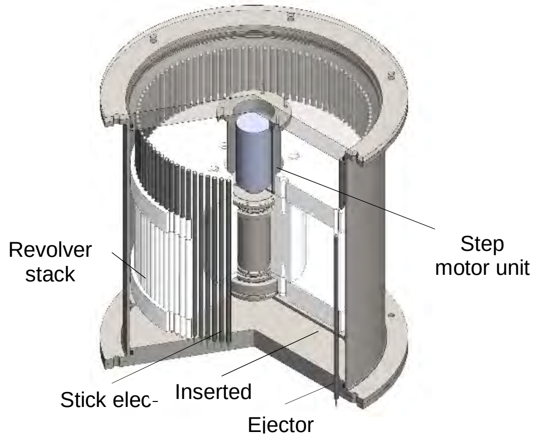

Fig. 9 Electrode stack

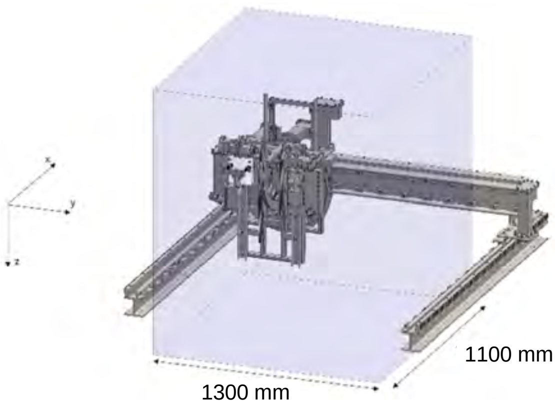

Fig. 10 Working area

The entire structure of the multi-axis welding system in the pressure chamber is shown in *Fig. 11.*

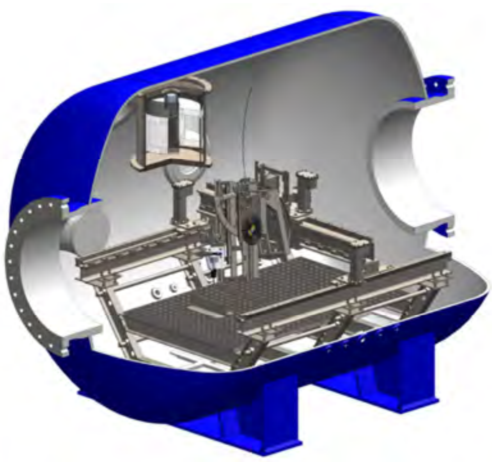

Fig. 11 Pressure chamber with multi-axis welding machine

The installation of the multi-axis welding equipment inside the 10.000 litres pressure chamber allows intensive research activities in the field of welding equipment to perform up to a water depth of 300 m. The wired system is shown in *Fig. 12.*

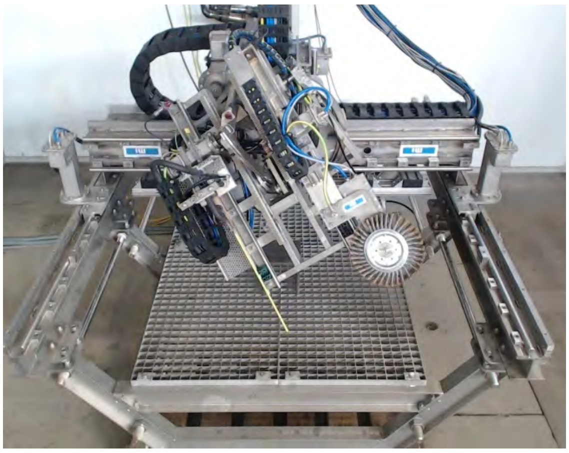

Fig. 12 Wired multi-axis welding machine

All electrical connections are made of special shielded cables to prevent disruptions and influences by inductive phenomena. The welding power source is an ELIN SWA 303 electric motor-generator-set (converter) with an adjustable open circuit voltage. To ensure the diver safety according to the diver restrictions, the open circuit voltage was fixed at 24 V. The welding power source is located outside the chamber and the welding cables are fed into the chamber.

For welding and storing of standard hydrogen samples an extension of the pressure chamber test rig had to be made. For this purpose a holding, feeding and stocking device was constructed, which is schematically shown in *Fig. 14*.

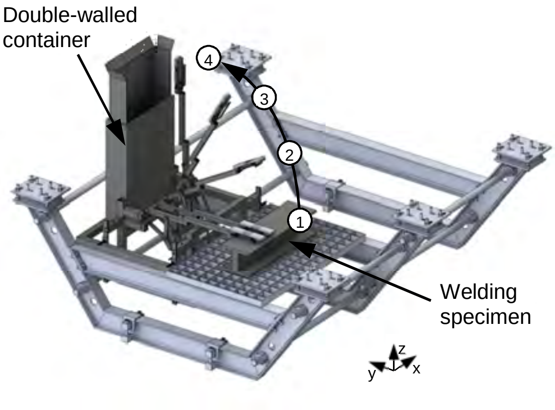

Fig. 13 Device for welding standard hydrogen samples under water

The device essentially consisted of five separately controllable levers with a mechanical mounting for standard welding specimen and a double-walled container for the storage of liquid nitrogen. In the initial position (1) the sample is fixed via a spring mechanism on the support rail. This serves as a ground connection of the electrical welding circuit. In this position, the water coverage is 500 mm, thus the complete stick electrode is wet during the welding process. Immediately after the end of the welding the lever is actuated by a pneumatic control system. The weld sample moves from position (1) on a circular-shaped path over (2) and (3) to the stopping position (4) *Fig. 13*, where the weld sample is released into the liquid nitrogen bath. The time between welding and the storage is about 5 s, which meets the requirements according to DIN EN ISO 3690: 2012.

3 EXPERIMENTAL RESULTS

The following tests were performed with a self-developed rutile electrode, named HK3 with a wire diameter of 3,25 mm and a length of 350 mm. This electrode was used, because of the knowledge of the different amounts of ingredients of the coating. This is information is not given for commercial stick electrodes. Therefore in previous working steps this developments and experiments for underwater welding in wet conditions were done. The work covers inter alia the development of suitable powder components, particle sizes, binder, coating and electrode pressing conditions to form a product which is applicable for the stable arc welding process under water.

The investigations show that the composition of the electrode coating and the water repellent varnish have a significant impact on the handling of the welding process and therefore on the quality of the weld.

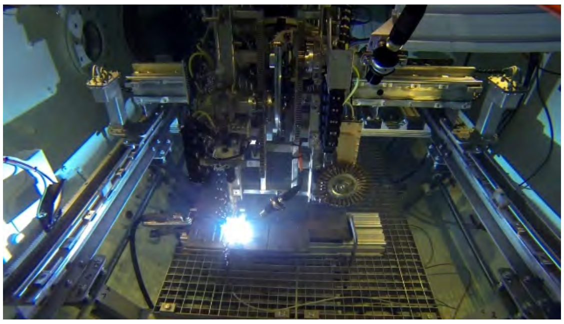

Fig. 14 Under water welding at 20 m simulated water depth

3.1 SYSTEMATIC STUDIES AT HIGHER WATER DEPTH

For the mechanical and technological characterization of the seam, welds were performed in an unmanned pressure chamber system in different water depth, *Fig.15* and *Fig. 16*. The metallographic cross sections show the uniform layer structure of a reproducible underwater welding and an increasing porosity with ascending water depth.

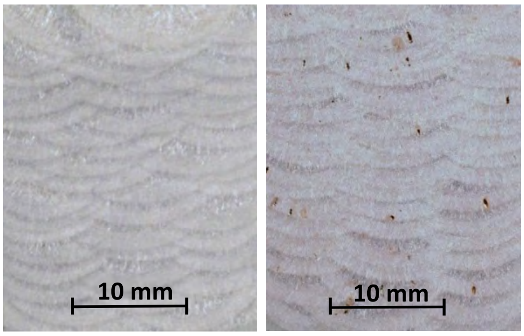

Fig. 15 Seam weld in 0,5 m (l.) and 20 m (r.) water depth

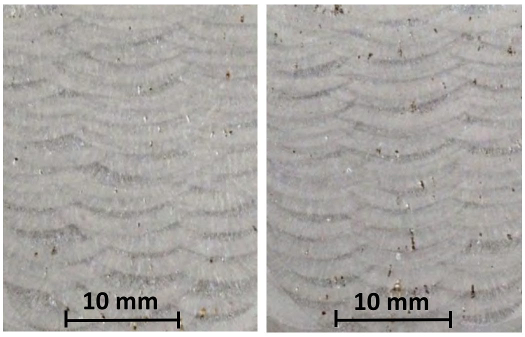

Fig. 16 Seam weld in 40 m (l.) and 60 m (r) water depth

3.1.1 Weld toughness

The toughness of the weld metal was determined according to DIN 2302: 2005 at a test temperature of 0 ° C. *Fig. 17* shows the average impact energy as a function of the welding depth.

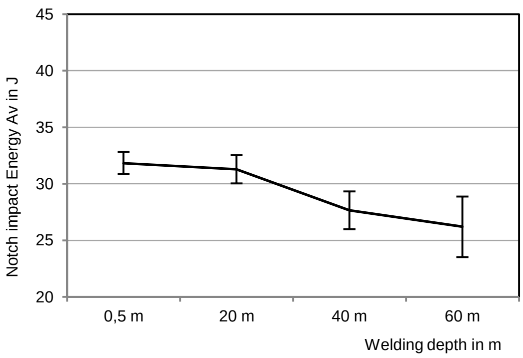

Fig. 17 Notch impact energy in dependence of the welding depth

The reduction of the impact energy with higher water depth is based on a combustion of the oxygen affine alloying elements (Si and Mn), because of the increasing dissociation of steam and carbon dioxide.

3.1.2 Diffusible hydrogen

To determine the diffusible hydrogen content for each water depth four slot welds with three test samples each (Material C: S355NL) were performed. *Fig. 18* shows the real procedure in the unmanned pressure chamber system.

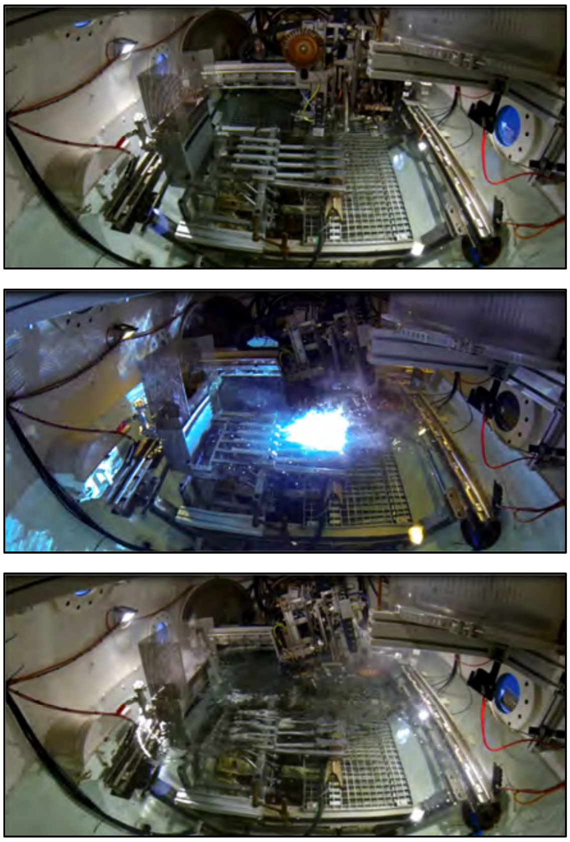

Fig. 18 Bead on plate weld for determination of diffusible hydrogen content

The depth-dependent results of the hydrogen measurement are displayed in *Fig. 19.*

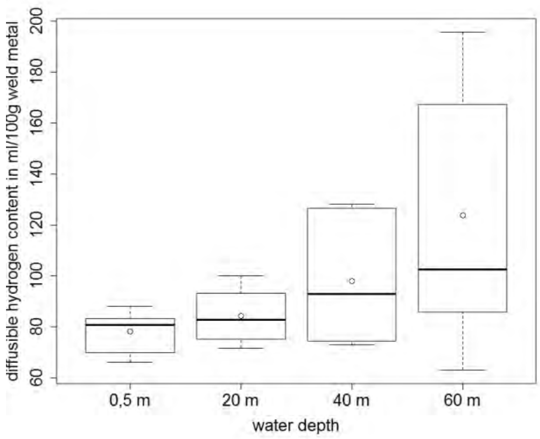

Fig. 19 Diffusible hydrogen content in the weld bead in dependence of the water depth

With increasing water depth, the median of the diffusible hydrogen content rises from 80,9 ml/100 g weld material (0,5 m) to 102,6 ml/100 g weld material (60 m). Furthermore, an increased dispersion of the hydrogen content can be seen at higher water depths (40 m and 60 m) due to the sinking process stability.

4 AKNOWLEDGMENT

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