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FRAUNHOFER RESEARCH INSTITUTION FOR LARGE STRUCTURES IN PRODUCTION ENGINEERING IGP

ANNUAL REPORT 2017/2018

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ACTIVITIES AND RESULTS OF THE FRAUNHOFER IGP

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EDITORIAL

Dear readers, dear friends of the Fraunhofer IGP,

Our institution here in Rostock has now been independent as the IGP for eighteen months. As Head of the Institute, I have been responsible for our Fraunhofer Research Institution for Large Structures in Production Engineering (IGP) for just over a year.

We have used this time to establish our independence without throwing our well-known strengths overboard. We have maintained and expanded our range of services and honed our profile in order to be a strong partner for our clients involved in the production of XXL components and small batches.

We focus on the unique feature of our institution of offering all the disciplines – from production methods and automation right up to company planning and the topics associated with Industry 4.0 and digital transformation – under one roof and of preserving our scientific profundity on the questions relating to these areas.
Despite our steady growth, we want to remain a competent contact for our clients here in Mecklenburg-Western Pomerania and for the typical branches of industry involved in large structures and in one-off production.

We wish to take this report as an opportunity to present our institutions, our team and a selection of our projects in which we developed marketable solutions together with our partners over the last year.
In order to give you visual insights into the Fraunhofer Institute as a whole, our institution and our working groups, we would also invite you to take a look at our new image film: "Introducing the IGP".

We hope you enjoy reading this report and that it generates new questions and ideas in your minds that we would be happy to help you to put into practice.
Use the report as a source of ideas for the innovations of tomorrow.

With kindest regards from the
Hanseatic and University City of Rostock

Prof. Dr.-Ing. Wilko Flügge
Director of the Fraunhofer IGP

Image film – Introducing the IGP

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ANNUAL REVIEW

EFB Research Advisory Board in Rostock
In September 2017, the EFB Research Advisory Board met for the first time on the premises of the Fraunhofer IGP. This board comprising representatives from industry and research decides twice a year on the quality of new research projects for which applications for funding have been made. For example, the EFB supports technological and application-oriented joint research in the fields of sheet metal processing by funding science and research.

40th IHK Technology Evening at the Fraunhofer IGP
The 40th event in the series "Technology evenings – know-how generates business" focused on the topic: Added value in Mecklenburg-Western Pomerania – made in plastics. For the 70 guests from business, research and politics, innovative plastics technologies for the present and future took centre stage. The research and development work in plastics technology conducted at the Fraunhofer IGP is even today an important basis for the regional economy.

Impressive appearance at the Blechexpo 2017
The Fraunhofer IGP participated in the International Trade Fair for Sheet Metal Working together with the EFB and held interesting discussions with numerous clients and potential clients. With the focus on the mobility sector, models of the large robot were presented that is used i.a. in the production and ship propellers and as clinching pliers for large plate thicknesses.

SPD State government visits Fraunhofer IGP
In spring 2018, the SPD ministers of the Mecklenburg-Western Pomerania state government met at the Fraunhofer IGP to find out more about the subject of digital transformation and its application. Prime Minister, Manuela Schwesig, met with representatives of the Fraunhofer IGP and IGD in advisory functions who made trendsetting contributions to the advancing digital transformation in small and medium-sized enterprises in Mecklenburg-Western Pomerania.

Lively discussions during the first reunion of former employees
Former employees met for the first time at the Fraunhofer IGP reunion. Some 20 guests took up the invitation from the professorships of Manufacturing Engineering and Joining Technology at the University of Rostock. The reunion quickly became a communication platform between scientists, both young and old, brought back memories and created scope for lively discussions about earlier, current and future research projects.

The IGP at the Hanover Trade Fair
This year again, the Fraunhofer IGP presented its latest research results at the Hanover Trade Fair, Germany's largest industrial fair. An innovative yet inexpensive solution was presented for digital structural condition assessment in shipbuilding, as well as a flexible large robot that simplifies the handling of very large loads with long reaches, thus meeting the demands of modern production processes in shipbuilding and the offshore industry.

The ILA and innovations for the future of air travel
The ILA Berlin was the centre of attraction for the international aerospace sector in 2018. The roughly 1100 exhibitors from 41 countries included the Fraunhofer IGP, demonstrating innovations for the future of air travel. The focus here was i.a. on the high-strength fibre-composite structures and load-bearing bonded joints that are indispensable in modern lightweight construction today.

The Fraunhofer IGP at the MV Day
Our Federal state presented itself in May 2018 at the 13th Mecklenburg-Western Pomerania Day (MV Day) in Rostock. As an important element in science and research, the Fraunhofer Research Institution for Large Structures in Production Engineering IGP formed part of the pagoda landscape on University Square. Together with the Fraunhofer IGD, the IGP presented the Fraunhofer Institute facilities in Rostock and reported on the latest research activities during the event.

Summer meeting of the Fraunhofer Alliance Production
A meeting of the Fraunhofer Alliance Production was also held in Rostock for the first time. The institute directors of the main production engineering institutions of the Fraunhofer Institute convened for their regular meeting at the Fraunhofer IGP in Rostock. On the previous evening, Prof. Martin-Christoph Wanner had officially retired from the Alliance during a sailing trip together on the Baltic Sea.

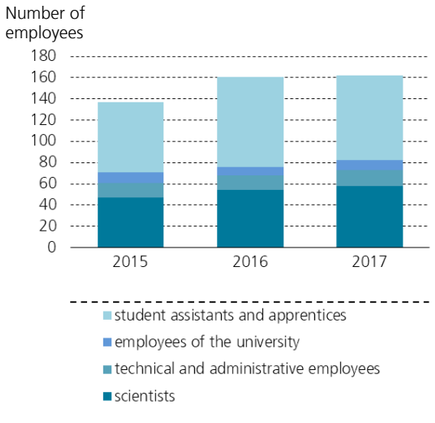
A breath of fresh air with the HANSE KONGRESS
In June 2018, entrepreneurs and scientists from Rostock, Mecklenburg-Western Pomerania and European Hanseatic cities were invited to take part in a new type of congress. The Fraunhofer IGP also had its part to play in this event. In addition to interesting pitching presentations on the subject of "Science, business and growth", the Fraunhofer Research Institution opened its doors to present the Institute and a selection of the latest projects to the international guests.

The IGP at the automatica
At the automatica 2018 everything was focused on innovative solutions in intelligent automation and robotics with pioneering key technologies for every branch of industry. The Fraunhofer IGP also presented cutting-edge research for automated production. For example,
the IGP demonstrated an application for the robot-based production of volume structures in shipbuilding using MIG/MAG welding processes.

Ceremonial inaugural lecture by Prof. Wilko Flügge
Prof. Wilko Flügge, Director of IGP, demonstrated his talent as a university professor and head of the Chair of Manufacturing Engineering, marking the official start of his professorship, even though he has already been lecturing at the University of Rostock since June 2017. Among the numerous interested guests were the Rector of the University, Prof. Dr. Wolfgang Schareck, and the Dean of the Faculty for Machine Engineering and Ship Technology, Prof. Dr. Manuela Sander.

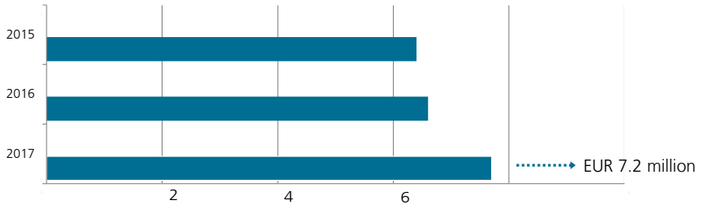
1 *Prof. Dr.-Ing. Martin-Christoph Wanner, former director of the institution, holding discussions at the automatica 2018*

THE INSTITUTE IN FIGURES



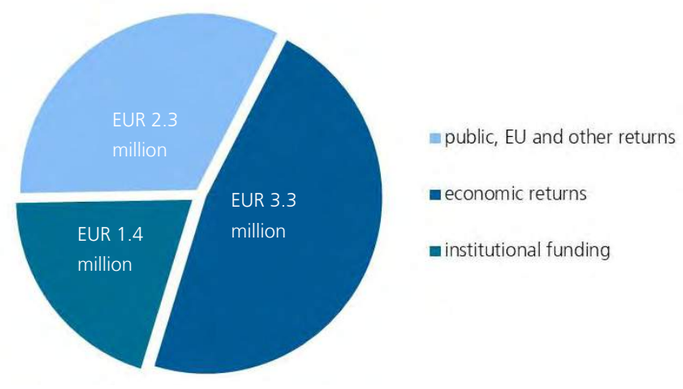
Employee development

The total number of employees at the Fraunhofer IGP rose in 2017 to 162. The majority of our scientists hold diplomas as graduate engineers or graduate industrial engineers. 80 student assistants supported the work of the Fraunhofer staff in 2017. Furthermore, the number of apprentices rose to three. In cooperation with the professorships of Manufacturing Engineering and Joining Technology, eight employees from the university work closely together with the Fraunhofer IGP in research and teaching. In addition, 27 placement contracts were concluded last year.



Overall budget

As in the previous years, the Fraunhofer IGP again had a balanced budget and a positive carry-over in 2017. The overall budget shows steady growth.



Financial returns

Earnings in 2017 totalled EUR 7 million, and with economic returns of 47%, our targets were again achieved. A further increase is expected for the coming year as well.

Equipment

The Fraunhofer IGP is growing! Not only the growing number of employees and the developments in budget and earnings bear evidence to the steady expansion, there are also changes in the size of our facilities: A decision was taken to start the fourth development phase for the further expansion of the institution with an investment volume of approx. EUR 14 million. Construction of the new building with a total area of approx. 2,000 m² has already started. On completion in 2021, the site in the south of Rostock will be able to boast new offices, laboratories and a new test workshop.

The Fraunhofer IGP currently has 2,545 m² of office and laboratory space in the Albert-Einstein-Straße in Rostock. The latest equipment for applied research and development is available in technical premises covering approx. 1200 m². The special facilities include laboratories for manufacturing engineering, automation and robotics, measurement technology, test engineering and inspection, monitoring and certification body, welding engineering, mechanical joining technology, adhesive bonding technology and a climate chamber, an area for virtual reality and a laboratory for Industry 4.0.

Further 2017 indicators

academic doctor degrees	3
conference presentations	57
publications	123

1 and 2 *Fourth construction phase of the Fraunhofer IGP, architectural drawing*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2

ORGANIZATION CHART

AS OF JULY 2018

FRAUNHOFER RESEARCH INSTITUTION FOR LARGE STRUCTURES IN PRODUCTION ENGINEERING IGP

Institute Management
Prof. Dr.-Ing. Wilko Flügge

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Measuring of Large Structures
Dr.-Ing. Michael Geist

Adhesive Bonding Technology, Fibre Composite Technology and Corrosion Protection
Dr.-Ing. Nikolai Glück

Inspection, monitoring and certification body according to LBO
Prof. Dr.-Ing. Ralf Glienke

Welding Engineering
Prof. Dr.-Ing. habil.
Knuth-Michael Henkel

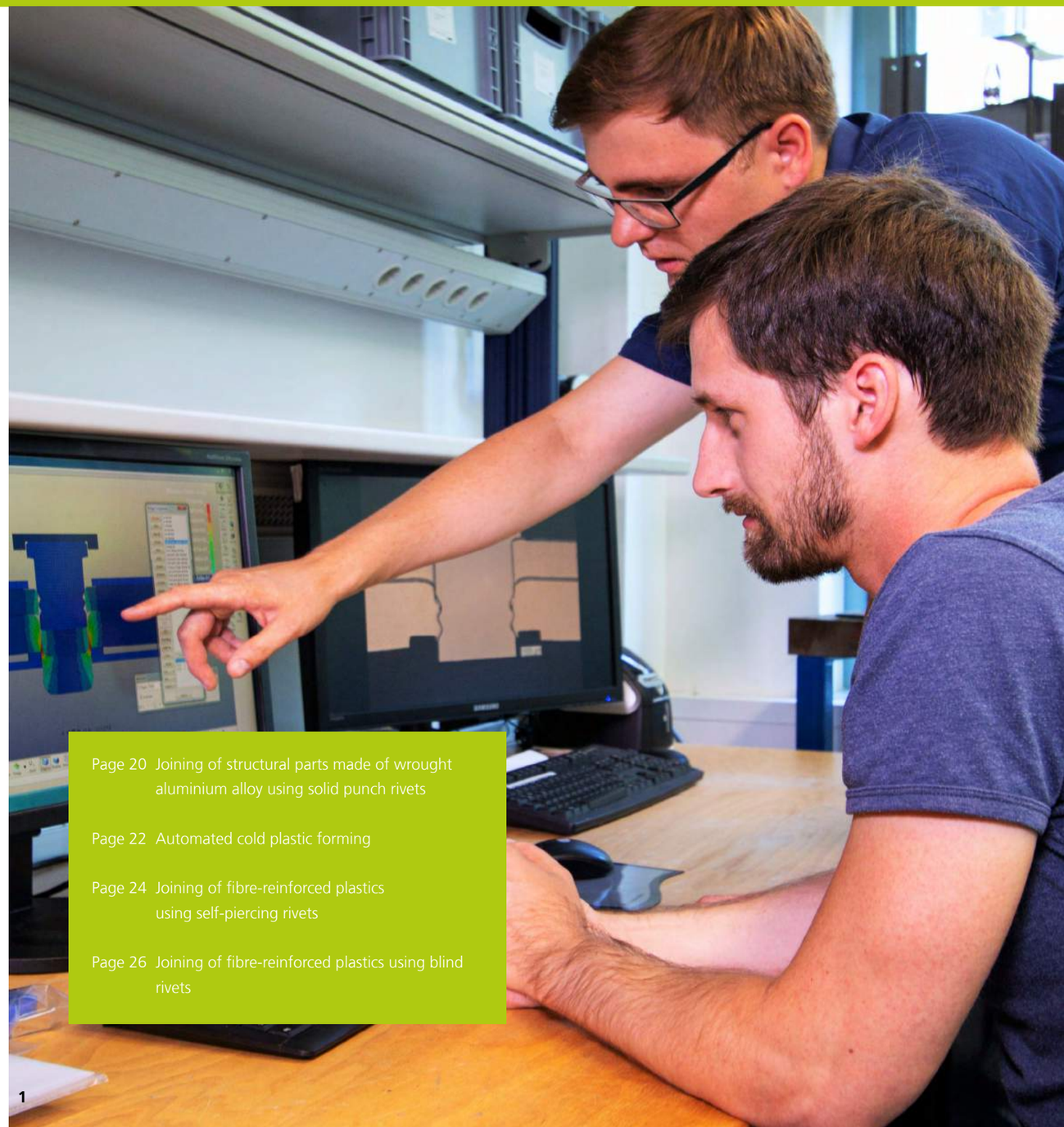
JOINING AND FORMING BY PLASTIC DEFORMATION

Main research focus and competences

The Joining and Forming by Plastic Deformation working group at the Fraunhofer IGP has two main research focuses.
The focus of the research in joining by deformation is on questions relating to the joining of lightweight construction materials, such as fibre reinforced or wrought aluminium alloys, both as joints using purely deformation and in combination with adhesive bonding. The main fields of application for the joining methods in question are automotive and aircraft industry.

The research covers both the initial qualification of the deformation or setting process of the joint and the analysis of the load-bearing capacity of the joint under static and cyclic loading and in the event of a crash. A particular focus here is on the fracture-mechanical evaluation of the joints with respect to crack initiation, crack propagation and fracture behaviour.
Furthermore, the properties of the joints are analysed over the service life, and topics such as corrosion resistance, leak tightness, electrical conductivity or the possibilities of (non-destructive) testing are examined.

The focus of the research into forming by plastic deformation centres on fundamental questions of forming and deformation of component structures. The main emphasis here is on the development of prediction models and the derivation of process control concepts for cold and hot plastic forming, predominantly for the forming of large steel plates with material thicknesses of more than 5 mm. These have to be evaluated and optimised with respect to their real-time capability for integration into machine control systems.



1 *Thomas Nehls and René Dukat examine the results of a solid punch riveting process*

Group heads

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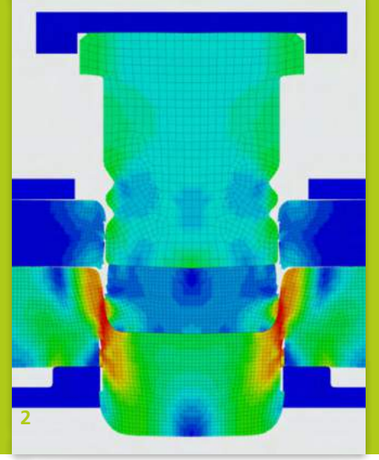

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JOINING OF STRUCTURAL PARTS MADE OF WROUGHT ALUMINIUM ALLOYS USING SOLID PUNCH RIVETS

Challenge

In the aviation, rail vehicle and automotive sector there is a requirement for efficient joining processes in combination with a reduction in the weight of the structure itself. In order to meet these demands, wrought aluminium alloys are increasingly used for structural components, joined by plastic deformation processes. Solid punch riveting has proved to be an efficient method. The development of solid punch rivets of high-strength aluminium alloys offers great optimisation potential for this field of application, since it provides a significantly improved life-cycle management and an optimisation of the corrosion resistance of the joints.

Proposed solution

Material characterisation

A solid punch rivet of a high-strength aluminium alloy is developed by a suitable choice of an aluminium alloy for the rivet material and its optimum adaptation to the joining application by means of appropriate heat treatment parameters.
During the setting process, the solid punch rivet punches its way through the parts to be joined, and the material of the joint parts flows into the circumferential grooves of the solid punch rivet. Due to the high local stresses, the rivet material has to be modified with heat treatment to obtain high strength with adequate forming capacity.
This modification presupposes precise knowledge of the aluminium alloys available for the joint elements and a detailed evaluation of typical joint part materials that determine the boundary conditions for the joining application. The necessary indicators are generated here from the hardness test, the quasi-static and cyclic examinations as well as the optical emission spectrometry for determining the chemical composition.

Numerical and experimental geometric optimisation

In addition to the choice of material and the heat treatment, the geometry of the solid punch rivet has a crucial influence on the setting process and the characteristics of the joint during solid punch riveting. High local stresses exist during the punching phase at the foot of the rivet and during the forming phase at the grooves of the rivet. A selective geometry modification based on numerical simulations enables the solid punch rivet to be optimally adapted to the joining application. In order to validate the simulation results, experimental studies are performed focussing on examining the maximum punching forces for different joint part materials, setting trials using solid punch rivets with optimised rivet geometry to determine the characteristics of the joint and the process parameters.

Determination of the process limits

The determination of the process limits focuses on the lateral and angular offset. The permissible limits for these parameters have to be determined in order to ensure optimum fastening point characteristics without overloading the aluminium solid punch rivet. These parameters are determined by numerical simulation.

Evaluation of the joint

The evaluation of the joint with respect to crack formation and load-bearing capacity are the final quality criteria. Optical analysis methods are used for this, while static and cyclic load-bearing capacity characteristics are determined in the test laboratory at the Fraunhofer IGP. The next step will be a comparison with joints produced using conventional steel solid punch rivets in order to allow the user to assess the test results.

Outlook

The development of a high-strength aluminium alloy solid punch rivet offers the possibility of joining structural parts of wrought aluminium alloys using the same material. The selective choice and modification of the rivet material and the detailed evaluation and optimisation of the rivet geometry allow the process limits of these joints using the same materials to be maximised. For the user this means a further field of application for aluminium solid punch rivets with the possibility of substituting conventional steel solid punch rivets. In order to achieve this, the research project aims to determine specifications for the process limits and to evaluate the joint with respect to its load-bearing strength characteristics. This leads to the targeted reduction in the structure weight and the advancement of lightweight construction. Furthermore, an improved life-cycle management and an optimisation of the corrosion resistance of the joints are achieved.

Participating partners

University of Rostock, Rostock

1 Solid punch rivet element
2 Numerical simulation of a solid punch riveting process

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Funding

The project "Joining of wrought aluminium alloy structural components using high-strength aluminium alloy solid punch rivets" is being financed and supported as a project of the Industrial Community Research in the Stifterverband Metalle e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

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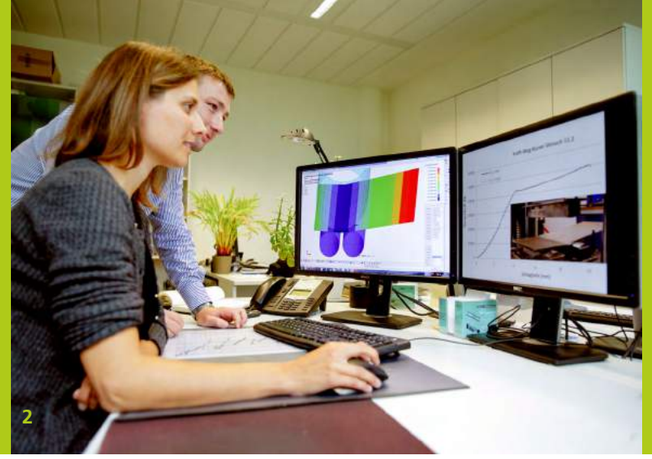

2

AUTOMATED COLD PLASTIC FORMING

Background

Three-dimensional forming of heavy plate for shipbuilding, facade construction, mouldmaking and the field of renewable energies involves a multi-step cold plastic forming process with free bending. The heavy plates are positioned here using a crane system. During forming, the crane system and the feed movement of the forming tool are controlled exclusively by the operator on the basis of his experience. Only templates in combination with the classic light gap method can be used here for quality assurance. In order to increase the efficiency of the process planning based on the purely subjective discretion of the plant operator and to create a possibility for archiving the wealth of experience, the research project focuses on the automation of the handling system.

Approach

Prediction of the plate deformation
Automated planning of the forming steps requires a possibility of computing time-optimised prediction of plate forming due to the contact with the tool. An approach of simplified geometric modelling is therefore applied in which the characteristic forming behaviour during free bending can be simulated using suitable geometric model parameters.
Identification of the model parameters in relation to the influencing factors of the cold plastic forming (material, geometry, contact position, etc.) involves the use of an artificial neural network that is trained as part of the experimental and numerical studies into practice-oriented forming tasks. The prediction model also has an interface for automatic correction of the prediction and the artificial neural network.

Automation of the process planning
On the basis of the forming prediction, an automated process planning system can be developed which can determine the necessary steps for any required geometries. An arithmetic approach to the simulation of the material-specific flow behaviour also allows the influence of strain hardening to be taken into account during the process planning. Subsequent sorting of the planned forming steps enables the cost effectiveness to be sustainably increased, as the time-intensive handling for positioning the heavy plate above the forming tool is reduced.

Recording of the real forming behaviour using optical measurement methods
Laser scanners allow the forming process to be continuously monitored. The optimal positioning of laser scanner for different plates ist determined on the basis of a field of view analysis, so that shadowing is avoided. In addition to automatic performance of the three-dimensional measurement, algorithms for automatic alignment of the point clouds and data processing are also being developed.

Intelligent crane control for precise plate positioning
An intelligent crane control system is required for precise positioning of the heavy plate above the forming tool with which direct implementation of the automated process planning can be assured. Simulation of the inertia characteristics enables the undesirable load swaying during acceleration and braking of the heavy plate to be significantly reduced.

Outlook

Automation of the cold plastic forming of heavy plates offers the possibility of objective control of a production process that until today has been purely subjective. The development of an automated database will also allow the time-intensive training of new machine operators to be significantly reduced. The continuous comparison of the predicted and the actual forming enables immediate compensation of supplier-specific fluctuations in the material properties and a long-term increase in the model precision. The process simulation allows the required production time to already be estimated at the planning phase, even when manufacturing unique parts, and hence machine utilisation to be increased, as the lead times can be planned more accurately.

Participating partners

Ostseestaal GmbH & Co. KG, Stralsund; University of Rostock, Rostock

1 *Forming press with crane for three-dimensional forming of heavy plates*
2 *Development of the automated process planning*

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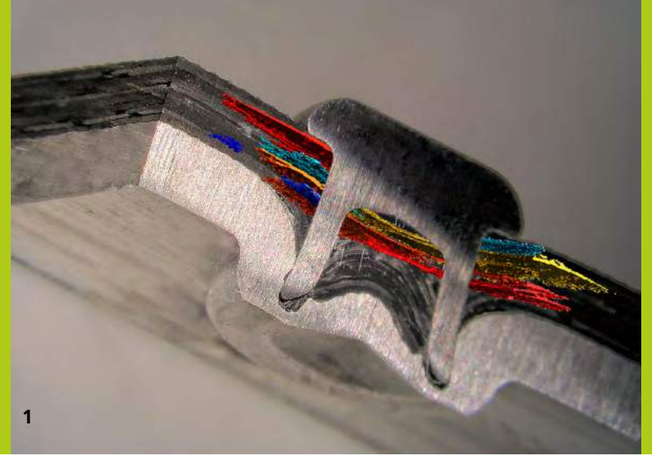
Funding

The project “Handling system for automated cold plastic forming” is being funded with grants from the European Regional Development Fund (ERDF). It is being supervised in accordance with the Guidelines for the Promotion of Research, Development and Innovation of the Ministry of Economic Affairs, Building, and Tourism Mecklenburg-Western Pomerania by the project manager, the Technology Advisory Institute (TBI).

EUROPÄISCHE UNION
Europäischer Fonds für regionale Entwicklung

Mecklenburg Vorpommern
MV tut gut.



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JOINING OF FIBRE-REINFORCED PLASTICS USING SELF-PIERCING RIVETS

Status quo

When it comes to the joining of metal structures and fibre-reinforced plastic composites, self-piercing riveting has come increasingly into focus as a joining method requiring no prepunched holes as its high automation capability is extremely suitable for use in large-scale production in the mobility sector and ensures high process reliability with short process times. However, the punch riveting process induces damage in the FRP composites. This damage includes local fibre and matrix fractures as well as widespread delamination that can significantly reduce the structural load-bearing capacity of the composite material and the joint. At present there are deficits in the reliable prediction of the setting process-induced damage and the uncertainties concerning the relationships arising out of the characteristics of the joint and the resulting load-bearing capacity under fatigue loading.

Approach

Quantification of the damage resulting from the setting process

The initial damage caused by the setting process is a key aspect that has to be taken into consideration in the analysis of mechanical joints in FRP. Analysis strategies are required here that allow a quantitative assessment of the setting process-induced damage in the FRP using the right measurement technology and evaluation methods.

Quantification of the damage caused by the setting process is necessary for two reasons: On the one hand, the development of numerical simulation models for prediction of the joint characteristics and the damage requires a basis for validation, and on the other hand a further analysis of the load-bearing capacity necessitates a characterisation of the basic condition of the damage due to the setting process. The relationships between the load-bearing capacity, in particular due to fatigue, and the setting process-induced damage could then be derived from this.

Numerical simulation of the punch riveting process

A large number of numerical modelling approaches exist for determining the joint characteristics and predicting the load-bearing capacity for metallic construction materials. They cannot be directly transferred to the forming and joining of FRP with metals, due to the complex anisotropic properties and damage modes of the FRP. An appropriate material characterisation and parameterisation is therefore necessary in order to be able to simulate the various failure modes during punching. In close cooperation with the Institute of Solid Mechanics at the TU Dresden, practical simulation approaches are developed with the goal of an efficient simulation of the punch riveting process in FRP/metal materials.

1 *Self-piercing punch riveted joint in fibre-reinforced plastics and aluminium with indication of the setting process-induced delaminations*

2 *Damage analysis using scanning electron microscopy (SEM)*

Damage mechanisms of the base materials

The determination of characteristic indicators is absolutely essential for successful modelling of the FRP material. For this, the necessary damage states have to be selected on the basis of experimental studies and to identify the damage parameters necessary for the model parameterisation using standardised testing concepts.

The material characterisation not only under quasi-static but also fatigue load provides an extensive insight into the damage mechanisms of the FRP composite. These findings form the basis for further load-bearing capacity studies on FRP/metal joints produced by plastic deformation.

Outlook

The studies are intended to give the user faith in the application of punch and deformation-based joining processes using FRP as joint partner. The efficient evaluation routines and modelling strategies allow the results to be transferred to other FRP materials and joint constellations, and offer the possibility of producing an application-optimised joint using FRP and metal.

Participating partners

Technical University of Dresden, Dresden

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Funding

The project “Modelling strategy for application-oriented simulation of punching joining processes with FRP hybrid structures” and “Fatigue strength of self-piercing riveted FRP/metal hybrid joints” are being financed and supported as projects of the Industrial Community Research in the Research Association EFB e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

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BLIND RIVETED JOINTS WITH FIBRE-REINFORCED PLASTICS

Motivation

Efforts to reduce structure weight in various sectors of industry are leading to an increased use of multi-material solutions that include both light alloys and high-strength steels as well as fibre-reinforced plastics (FRP). Application of the multi-material design presupposes joining methods that ensure a material-optimised and at the same time efficient use.
In the body shops of car manufacturers, blind rivet systems are used i.a. for prefixing component structures. A major demand for these joints is to ensure the overlapping of the holes in the parts to be joined. The accumulation of form and position tolerances of the individual parts into tolerance chains, however, can often lead to unfavourable joint configurations. As a result, damage can be observed in both the joining element and the joint parts in joint pairings with fibre-reinforced plastics.
The research project aims to identify the application limits for existing blind rivet systems and to give the user design tips for joint configurations.

Proposed solution

Identification of damage mechanisms
A blind rivet joint of FRP and aluminium serves as the object of the research work. The influence of key joint parameters on setting process-related damage is systematically investigated using this exemplary joint. The parameter range is expanded by the use of different versions of blind rivet elements and joint materials. Metallographic microsections allow cracks in the joint element, fibre breaks or delaminations of the matrix of the composite material in the area of the joint to be detected. The findings serves as input variables for the further trials to be carried out and to enable trends in the effect of the joint parameters observed on the extent of the setting process-induced damage to be formulated.

Load-bearing capacity studies
Experimental studies of the load-bearing capacity of the blind rivet joints complete the damage analysis. Starting from the previous observations, specimens are then appropriately preconfigured for each joint element and tested under both quasi-static and fatigue loading. Of great importance here is the relationship of the effects of the generated damage under fatigue load as occurs under real conditions during operation.

Numerical simulation of the blind rivet setting process
Appropriate geometry models of the rivet elements in question are prepared for the simulation of the setting process and the material properties of the individual rivet parts (rivet body, rivet mandrel) are determined experimentally. In order to simulate the setting process-induced damage in the FRP material, a material model is developed that takes into consideration the material-specific effects with respect to deformation and failure.
In a further work step, the simulated blind riveting processes are validated by combining the models of the rivet and joint partners using technological parameters such as force/displacement curves and local deformations and geometric parameters of set rivet and joint parts for different joint configurations and comparing with the experimental findings.

1 *Body structure of an Audi R8 with FRP parts*
2 *Aluminium/FRP blind rivet joint, allowing for form and position tolerances*

Outlook

Using the parameterised model of blind rivet and CFRP, material and geometric modifications can then be made selectively to the joint system. The goal is to identify levers for optimisation of the blind riveting process with which setting process-induced damage can be selectively reduced or even avoided. The development and subsequent production of blind rivet demonstrators that have, for example, a better blind rivet convolution should validate the findings obtained from the simulation. Further results of the research include not only a corresponding prediction of joint and damage development, but also precisely formulated demands for the joining of fibre-reinforced plastics with blind rivet elements taking into account different boundary conditions. These will ensure that high-quality blind riveted joints can also be produced in composite materials.

Participating partners

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Funding

The project “Requirements for blind rivet joints with FRP” is being financed and supported as a project of the Industrial Community Research in the Research Association EFB e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

MECHANICAL JOINING TECHNOLOGY

Main research focus and competences

Growing demands on the manufacture of energy and resource-efficient products and environmental aspects are leading in many branches to an increasing use of lightweight construction concepts. The associated use of new types of material has given rise to a renaissance in particular of mechanical joining technologies in recent years. In order to give due consideration to this development, the Fraunhofer IGP is developing innovative and cost-effective solutions to the associated problems.

The field of mechanical joining technology involves various research focuses in light alloy and steel construction, in rail vehicle construction and in general motor vehicle and machine engineering. We elaborate branch-specific solutions together with our clients. The right choice and command of the joining methods go a long way to determining the functionality, reliability and safety of a construction right from the start of the product development. At the same time, the optimum joining technology for the particular application helps to save costs and material during production and use. The scope of activities extends from the advice on the choice of the optimum joining technologies through the analysis of the load-bearing strength right up to the derivation of suitable dimensioning rules, depending on the demands of the particular application.

The theoretical considerations are backed up by the accredited test laboratory of the Fraunhofer IGP that, with its modern testing technology, is able to carry out extensive experimental studies into materials, fasteners, joints and coating systems under standardised conditions.

1 *Andreas Ebert and Thomas Gerke discussing the results of preload tests*

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RELIABILITY OF SLIP-RESISTANT CONNECTIONS IN STEEL STRUCTURES

Motivation

The international project "Execution and reliability of slip-resistant connections for steel structures using carbon steel and stainless steel - SIROCO" examines the behaviour of slip-resistant prestressed connections of carbon steel and stainless steel. Slip-resistant connections are predominantly employed in constructions subject to shear stresses with loads exerted by vibrations, with and without load reversal.

A far more cost-effective design of slip-resistant prestressed connections in steel structures is possible if higher values can be achieved for innovative coatings compared with the standardised coefficients of static friction in DIN EN 1090-2. The experimental study and the interaction of pretightening force and coefficient of static friction are of immense importance also with a view to maintenance-free slip-resistant prestressed connections.

Applications can be found, for example, in bolted bridges and in longitudinally split towers of wind turbines or lattice masts. An important role is played here by the method used to determine the coefficient of static friction. The rules for this are defined in Annex G of DIN EN 1090-2, but cannot be directly applied to innovative coating systems.

In addition, the tests are very complex and the so-called displacement criterion to determine the slip load can vary, depending on the test specimen size. In the standard, however, this displacement is defined at a fixed value of 150 µm. The displacement criterion is now being revised to ensure improved testing. The approach to the execution and evaluation of the extended creep test according to DIN EN 1090-2, Annex G.5 is also considered and revised in detail.

Furthermore, the method for determining the coefficient of static friction is evaluated with respect to the following parameters: Test speed, level of pretightening force, tightening method, pretreatment of the friction surfaces (sandblasting, hot-dip galvanising, alkali/ethyl silicate zinc coating, thermal spraying with aluminium/zinc and combinations), criteria for determining the slip load and determination of the loads for extended creep tests. Improvements in the method for determining the coefficient of static friction were formulated that have already been partly incorporated into the revision of EN 1090-2.

The use of bolts in slip-resistant connections, both of stainless steels, was investigated with respect to the creep/relaxation behaviour, the pretightening force losses, the tightening behaviour and the slip-resistant load-bearing effect for austenitic, duplex and super-duplex stainless steels. The results have shown that stainless steel bolted connections can generally be pretightened, and that "fretting" can be prevented by the use of suitable lubricants and tightening methods. High practical coefficients of static friction were determined for sandblasted surfaces using the method defined in Annex G of DIN EN 1090-2. Recommendations were then formulated for the design and production of slip-resistant connections and for revisions to EN 1993-1-4, EN 1993-1-8 and EN 1090-2.

1 *Evaluation of the extended creep test according to DIN EN 1090-2, Annex G*

Goals

Rules followed to date for slip-resistant connections in steel structures are defined in DIN EN 1090-2 only for structural steels and for a few friction surface coatings. For other surfaces or for higher coefficients of static friction, special tests have to be carried out in accordance with DIN EN 1090-2, Annex G, whose standardised performance raised a few questions that were clarified during the course of SIROCO. An improved method for testing the coefficient of static friction μ according to EN 1090-2, Annex G was developed and incorporated into the existing draft standard.

Furthermore, modern and innovative connecting elements such as lock bolts and H360 bolts was successfully employed in slip-resistant prestressed connections and comparative studies were carried out on joints with high-tensile prestressed bolts.

The main goals of the project, the improvement in the cost-effectiveness of slip-resistant connections for structural steel, taking into consideration new and innovative bolting and pretightening methods and innovative coating systems, and the closing of important gaps in the knowledge of hot-dip galvanised steel joints were achieved.

On the other hand, these existing rules apply only to connections of structural steel, so that extensive and comparative studies were carried out into the pretightening and load-bearing behaviour of slip-resistant prestressed connections of austenitic, duplex, lean-duplex and super-duplex steels were carried out.

For the first time, dimensioning rules were elaborated for the pretightening force for bolted connections of stainless steels using bolts also made of stainless steel, and rules were formulated for the execution of the connection.

Participating partners

Arup, London; Bumax AB, Åshammar; EGGA, Reddicroft; Institut für Korrosionsschutz Dresden GmbH, Dresden; Outokumpu Stainless AB, Avesta; Outokumpu Stainless Oy, Tornio; SCI Steel Knowledge, Ascot; Technical University of Delft; University of Duisburg-Essen, Duisburg; VTT, Espoo

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2

LOSS OF PRELOAD OF FATIGUE LOADED PRELOADED BOLTED CONNECTIONS

Introduction

In order to ensure the load-bearing capacity or serviceability of structures over their life cycle, maintaining the prescribed pretightening force in the bolted joints is crucial. The joints consequently have to be inspected at regular intervals and retightened, if necessary. In order to define and prolong service intervals, the preload losses therefore already have to be realistically estimated during the dimensioning of a joint. There are numerous reasons for preload losses, but the proportion of preload losses due to cyclic loading is still more or less unknown.

Proposed solution

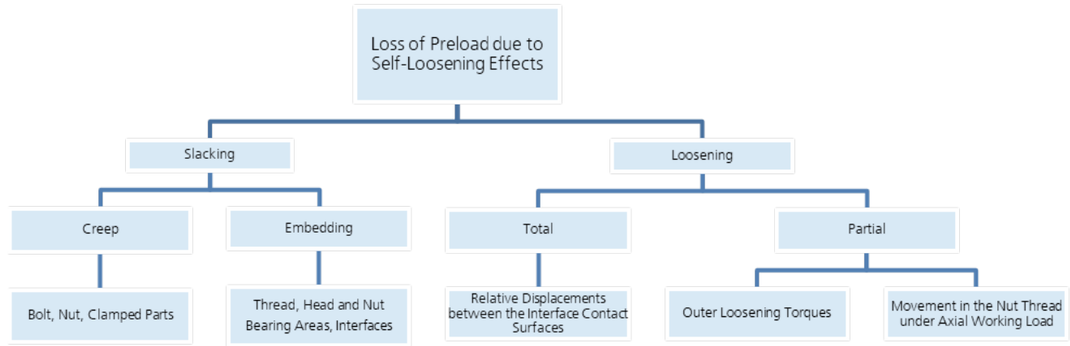
During the research project, the proportions of preload losses due to settling and to cyclic loading were determined for a large number of practical joint configurations. The preload losses over time were examined for non-slip prestressed joints and tensile prestressed joints using various connectors, tightening methods and surface pretreatments. Particularly with the cyclic stresses, attention was paid that the loads were defined to reflect the situation in the real application. The determining factors for the preload losses were identified and the extrapolated and statistically validated preload losses for each joint configuration were determined.

Benefits

Cause-specific determination of the preload losses in preloaded joints is intended to give companies the chance to already take preload losses into consideration at the time of dimensioning of the joints so that maintenance intervals can be extended or mechanically maintenance-free joints can be produced. At the same time, the bolted joints can be designed to allow optimum use of the remaining preload.

Outlook

Following great interest on the part of industrial companies, a follow-up project is planned during which the database should be expanded. In addition, further studies with variable amplitude loading (multi-amplitude cyclic loading) on preloaded connections are necessary, as these correspond most closely to the situation in the real application.



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1 *Ferris wheel with non-slip prestressed joints*
2 *Lattice tower of a wind turbine with slip-resistant connections*
3 *Causes of preload losses*

Participating partners

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The project "Development of a concept for determining preload losses in preloaded bolted connections under fatigue loading" was financed and supported by the Research Association FOSTA e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

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2

INCREASE IN LOAD-BEARING CAPACITY BY THE USE OF LOCKBOLT SYSTEMS

Introduction

Joints with lockbolts are dimensioned in accordance with the DVS-EFB Code of Practice 3435-2 in conjunction with DIN EN 1993-1-8 (EUROCODE 3) and Guideline VDI 2230 Sheet 1. Until now, however, the code of practice has considered only the basic cases of the loading that can be divided into pure concentrically and axially stressed joints (tensile loading) and pure transversely stressed jointS (shear loading).
Nevertheless, a large number of applications are encountered in practice in which the actual loading does not correspond to the basis cases. In most structures in steel construction, machine engineering, commercial and rail vehicle construction, joints are therefore found that are not subjected to purely concentric stresses or purely transverse stresses. As a rule, the joint element is subjected to a certain eccentricity due to the design, such as L-flanges in tubular steel towers of wind turbines where the joint element is subjected to bending stresses in addition to the pure tensile loading. The use of eccentrically-stressed connections with lockbolts in load-bearing and hence often safety-relevant structures frequently presents design engineers with a challenge. For this reason, the now completed project at the Fraunhofer IGP focussed on the systematic examination of the load-bearing behaviour and failure mechanisms of lockbolt joints under eccentric loading. On the basis of the results achieved, an increase in the load-bearing capacity is to be expected i.a. in the fatigue limit state for eccentrically loaded lockbolts compared with conventional bolted joints.

Objective and proposed solution

The goal of the research project was therefore to give users of the lockbolt technology an extension to the design rules that enables users to reliably and cost-effectively dimension and design lockbolt joints according to the eccentric loading to be expected over the service life, both analytically and using the finite elements method. For this, systematic experimental and numerical investigations into the load-bearing capacity under tensile and cyclic loading were necessary. The main focus here was on the non-linear load curve on lockbolt joints. In addition, a comparison with conventional bolted joints was carried out.
Dimensioning parameters were selectively derived from the findings gained during the experimental and numerical studies. These can be used to verify the limit conditions of the load-bearing capacity and fatigue strength of lockbolt joints exposed to eccentric axial loading. The goal in this context was to determine the key failure mechanisms and to define a notch situation. The subject of the research project were steel lockbolts in nominal diameters of M16, M20 and M36 and the joints produced using these.

1 *Setting of the lockbolt*
2 *Numerical simulation for analysis of eccentrically-stressed connections with lockbolt systems*

Benefits

An increase in the load-bearing capacity by using lockbolts allows smaller dimensions to be used, such as for L-flanges in tubular steel towers of wind turbines with reduced eccentricity, offering the user significant savings in material input, service and maintenance. The extension of the dimensioning rules for eccentrically stressed lockbolt joints will in future reduce the amount of testing necessary, particularly for small and medium-sized enterprises. The findings will be incorporated into the DVS-EFB Code of Practice 3435-2 as an extension in the form of a dimensioning proposal and presented in a user-friendly manner.

Outlook

Applications for large nominal diameter lockbolts are to be found i.a. in modern wind turbines with large hub heights. Large hub heights make great demands on the performance of the towers, as these have to satisfy certain static and dynamic properties for reliable operation of the plant. In future, flange joints that exert eccentric loads on the lockbolts could be dimensioned using the finding from this project.
At present, however, there is a lack of know-how as to the load-bearing capabilities of such large-diameter lockbolt joints subjected to eccentric axial loads. The potential confirmed in the research project has to be extended and also confirmed for larger nominal diameters during further research activities in order to close the gaps in the knowledge with respect to the limit states of the load-bearing capacity and fatigue strength of lockbolt joints.
In addition to the dependence of the load-bearing strength, and in particular the vibration resistance, on the nominal diameter of the lockbolt, there is still a lack of know-how as to the influence of manufacturing and assembly-related imperfections on the eccentrically loaded lockbolt joint. In this context, not only the load-bearing strength, but also the sequential assembly of lockbolt systems, for example the closing of the flange gap imperfections in ring flange connections, has to be investigated with respect to the application of the installation pretightening force.

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Funding

The project “Increase in load-bearing capacity of eccentrically-stressed connections by the use of lockbolt systems” was financed and supported by the Research Association EFB e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

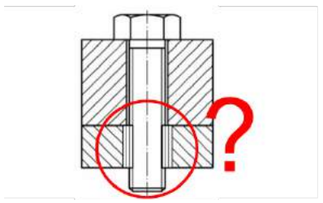
Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

2

THREADED INSERTS FOR LIGHT ALLOY SCREW FITTINGS

Motivation

Growing demands on energy efficiency and sustainability, and hence an increasing material mix, are to be observed in all products of machine and plant engineering, in automotive construction, rail vehicle construction, aerospace and also in lightweight metal construction in the building industry. The goal here is to reduce weight through the use of light metals such as aluminium, magnesium, titanium and their alloys, while at the same time still ensuring the repair and recycling capability of parts. In the light of this, separable bolted joints are indispensable and are therefore also widely employed.



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Benefits

In construction engineering, the goal is generally to use a small diameter bolt while making the best possible utilisation of the bolt material. This measure is designed to save weight, to lower the influence of size, to reduce eccentricity and to allow smaller bolts to be used, thus minimising the required installation space. The lightweight design objective is therefore being rigorously implemented in construction engineering.

Light metal constructions without bolted joints are barely conceivable today in a large number of technical applications. The group of users employing bolted joints with threaded inserts is thus correspondingly vast, extending from small to medium-sized enterprises (SMEs) that generally offer highly specialised products and act as suppliers, through the manufacturers of the threaded inserts proper who as SMEs themselves provide their technical know-how, right up to large companies.

On the one hand, the knowledge of the possibilities and limitations of the use of threaded inserts in light metals in the sense of fastening technology opens up new fields of application, and hence new fields of business. Calculation rules for threaded inserts formulated and validated by experimental studies generate acceptance and security for this technology by both the SMEs as suppliers and the users. The planned experimental studies lead on the other hand to the development of new technical innovations within the context of the lightweight design objective, and hence to conserving resources. These innovations help in particular SMEs to remain competitive on the market. This research project aims to tackle concrete problems facing the industry with regard to the use of bolted joints in light metal materials. For a technological solution in the form of the threaded inserts, expert know-how for the dimensioning of the threaded inserts is made available to the general public and pre-standardisation work is carried out. Fastening technology that is used extensively and a wide variety of forms in all branches of industry can thus make a significant contribution to improving existing products.

1 *Questions relating to the load-bearing capacity of multi-start thread engagement*
2 *Torque pretightening force study*

Outlook

The goal of the research project lies in experimental, numerical and analytical proof that the threaded inserts used in light metal can be used and dimensioned in the sense of the design principle of the bolted joint. The knowledge base is expanded in that for the first time, a statement as to the axial load-bearing strength of the self-tapping threaded inserts (and large-diameter wire threaded inserts (d > M16)) screwed into light metals is possible using the limit force concept, and that the calculation and design rules for intermeshing thread parts can be extended to include the thread inserts.

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Funding

The project “Threaded inserts for light alloy screw fittings” was financed and supported by the Research Association EFB e.V., and sponsored via the Working Group of the Industrial Research Association (AiF) as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

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EFB
DEUTSCHER SCHRAUBENVERBAND e.V.

ADHESIVE BONDING TECHNOLOGY, FIBRE COMPOSITE TECHNOLOGY AND CORROSION PROTECTION

Main research focus and competences

The Faculty of Adhesive Bonding Technology, Fibre Composite Technology and Corrosion Protection at the Fraunhofer IGP addresses both current joining issues of lightweight and composite construction and the development and adaption of production methods for fibre composite parts. Further main research focuses are the effects of ageing on materials, adhesive bonded joints and coatings by means of laboratory ageing in an artificial climate. In cooperation with the accredited test laboratory at the Fraunhofer IGP, materials, joints and coating systems are tested and qualified under standardised conditions. In addition, new testing methods for special applications are developed and employed.

In the field of adhesive bonding technology, the range of services offered by the IGP extend from the bonding-optimised design of parts and assemblies, through the planning and dimensioning of bonded joints right up to the development and qualification of the whole bonding process and the joint.

The focus in the field of fibre composite technology lies on the holistic optimisation of large fibre composite constructions such as the rotor blades of wind turbines, ship superstructures and applications in civil engineering. The work extends from the development of flame-resistant materials through production engineering up to the determination and calculation of indicators.

In the field of corrosion protection and artificial ageing, the focus at the IGP lies on the development and qualification of innovative corrosion protection systems with improved properties and the identification of ageing influences.

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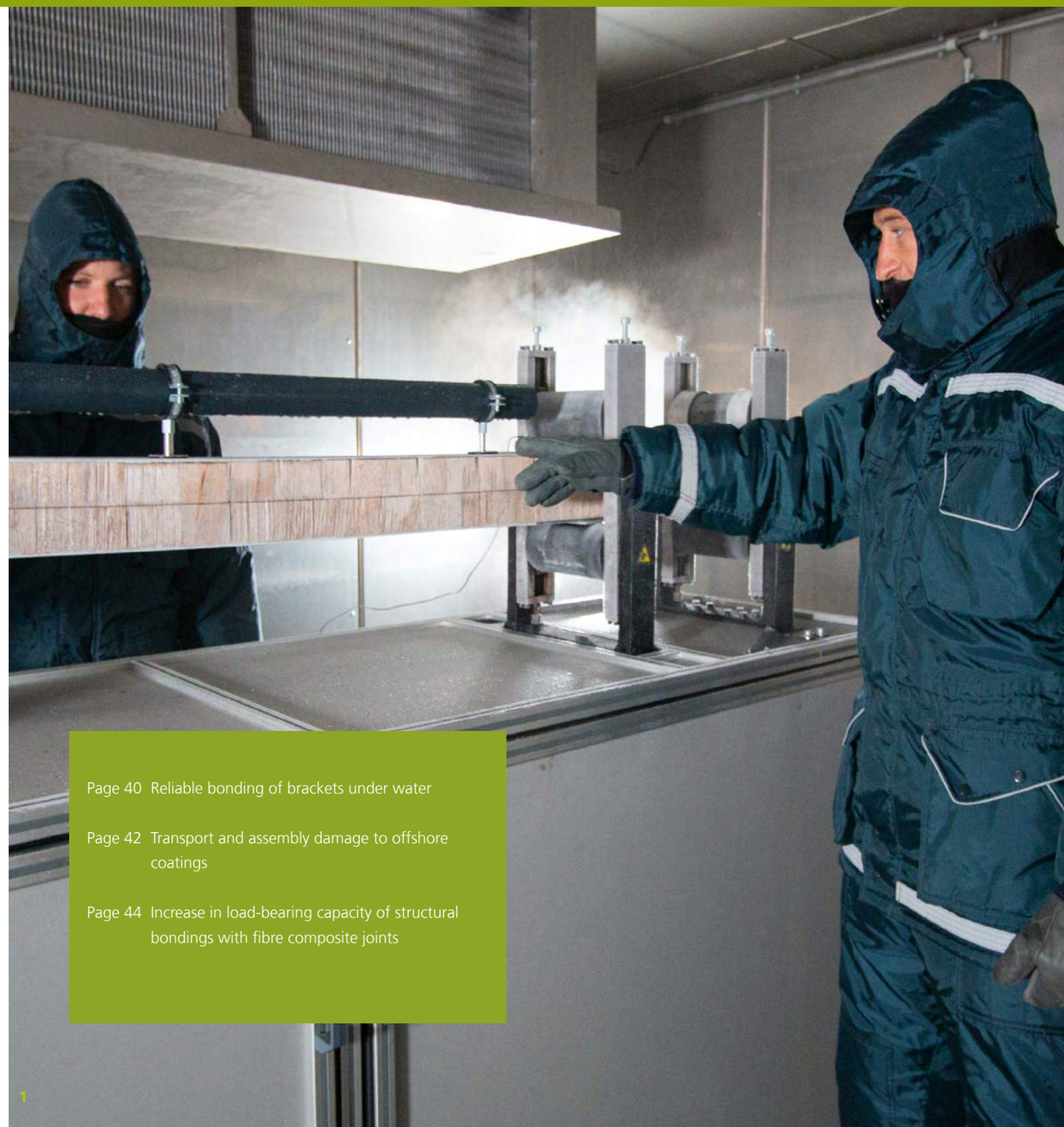
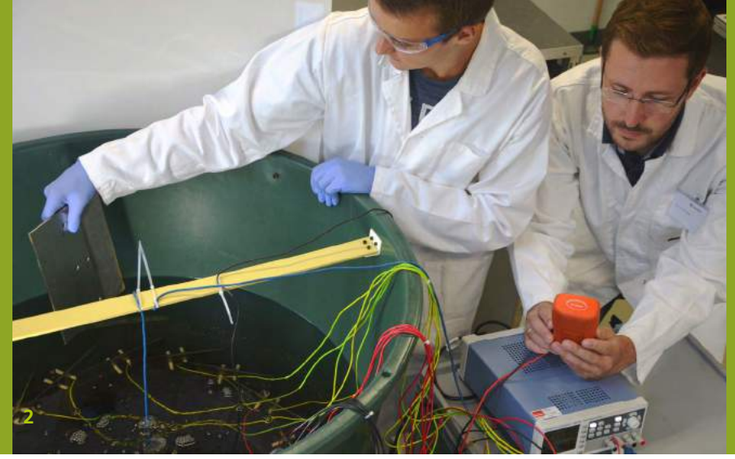


1 *Daniel Kelm and Ivo Drisga during the thermo-mechanical alternating load test on a composite girder in the IGP climate chamber*



RELIABLE BONDING OF BRACKETS UNDER WATER

Motivation

The operation and servicing of hydro-engineering systems, such as offshore structures, weirs or dams, but also the maintenance of ships frequently necessitate the subsequent installation of pieces of equipment under water. These can include i.a. cables, pipes, monitoring systems and measuring instruments. Brackets are then required for secure attachment that have to be retrofitted or replaced. Adhesive bonding, a method that has barely established itself to date in the underwater sector, can be used here as an alternative to underwater welding. As part of the underwater adhesive bonding project, solutions are developed to allow the corresponding adhesive bonding to be reliably carried out, taking into consideration process-relevant aspects such as suitable surface pretreatment and application methods, curing mechanisms and the long-term behaviour.

Proposed solution

Choice of adhesive for the underwater application
Already existing adhesive systems are used for the development of a robust underwater adhesive bonding process. A preselection was made on the basis of a defined requirement profile for underwater adhesive bonding in cooperation with adhesive manufacturers. Key considerations here were the stability of the curing process in contact with water and a long-term resistance of the load-bearing bonded joint to (salt) water. Further demands were, for example, a pronounced ability of the adhesive to wet the surface of the base material. This can be achieved with a particularly low surface tension of the adhesive.

Adhesive application under water
Underwater adhesive bonding has a further special feature, however, compared with adhesive bonding in the free atmosphere. In order to be able to create adhesion forces between the adhesive and the surface, not only dirt and loose particles have to be removed, but also water molecules have to be displaced from the surface that are adsorptively bound by the surface energy of the material to be bonded, before the application of the adhesive. During this project, the injection technology is used to eliminate these weak boundary layers. The object to be attached is first temporarily fixed, for example using magnets. During the process, the bonding gap created by spacers is sealed so that a cavity is created. The adhesive is then injected via a gate, and after complete filling of the bonding gap exists again via a gate directly into a riser. This step is combined with a prior purging of the cavity with compressed air. Pollution of the environment caused by mixing of the adhesive with the surrounding water can thus be avoided.

Ensuring the curing of the adhesive
The surrounding water influences not only the development of the bonding forces between the adhesive and the substrate, but can also impair the curing of the adhesive. This applies in particular to the chemically curing systems considered during the project, whether hot or cold-curing. Both systems generate heat during the course of curing. In the case of the cold-curing systems, this heat is sufficient to ensure adequate mechanical properties in the cured state. That is not the case with the hot-curing systems: Here additional heat has to be provided.
By comparison with adhesive bonding above water, an accelerated removal of thermal energy occurs under water so that it takes longer for the ultimate strength of the bonded joint to be reached. Furthermore, a lower resistance of the bonded joint to moisture and other media is to be expected, in addition to the poorer mechanical properties.
The solution to the problem can lie in the use of cold-curing adhesives whose mechanical properties are sufficient for the intended application, despite the underwater curing. Alternatively, hot-curing adhesives can be used that are selectively heated by means of special heating systems.

1 *Application trials in a seawater bath on brackets in different positions*
2 *Laboratory ageing under water of bonded specimens with integrated corrosion protection*

Outlook

The objective of the further research work is i.a. a long-term qualification of selected surface/adhesive combinations. For this, bonded samples are subjected to accelerated ageing in the laboratory. At defined intervals in time, exposed samples are taken and subjected to tensile testing to determine their mechanical properties. In order to validate the suitability of the accelerated ageing in the laboratory, samples of identical form are tested in near-shore coastal waters of the Baltic Sea at the same time. The results are used to describe the general ageing behaviour of the joint and to determine attenuating factors with which the strength of the bonded joint can be predicted for long-term use in open waters. On the basis of the real tests in combination with the determined attenuating factors and finite elements analyses, a catalogue of bracket classes with the respective maximal load-bearing capacities will be drawn up. This aid should simplify the use of the adhesive bonding technology in the underwater sector, and thus make a contribution to establishing the bonding method in this new environment.

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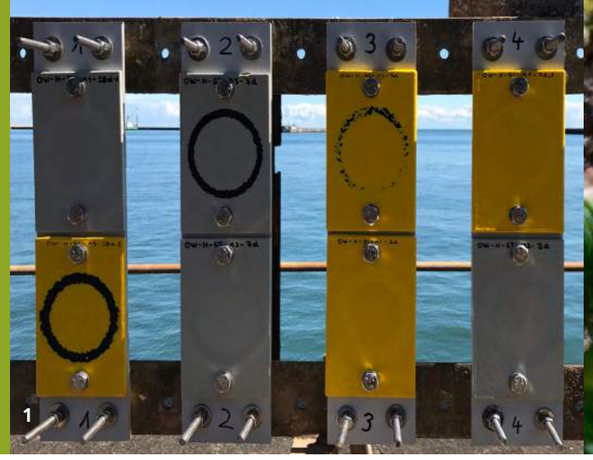
Funding

The IGF project “Development of a process for reliable bonding of brackets under water” of the Research Association for Welding and Related Processes e.V. (DVS) was funded via the AiF as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
DVS FORSCHUNG
aufgrund eines Beschlusses des Deutschen Bundestages



TRANSPORT AND ASSEMBLY DAMAGE TO OFFSHORE COATINGS

Challenge

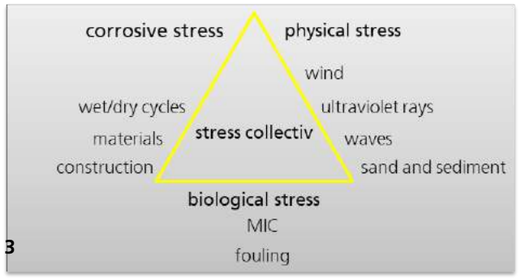
The repair of coating and corrosion damage on offshore wind turbines involves a great deal of time and organisation, as well as high costs. The avoidance of coating damage is therefore of great importance. Systematic examinations of 750 inspection points on offshore wind platforms in the North Sea and Baltic Sea showed that 30% of all the damage could be attributed to mechanical stresses. Results of inspections on offshore wind turbines in the North Sea and Baltic Sea after one to five years' operation showed that 46% of the damage was due to "mechanical damage after acceptance" of the finished and coated part.

The goal of the inspections was to categorise the damage, to make it evaluable under laboratory conditions and to determine the influence of mechanical damage on the remaining corrosion protection effect of coating systems.

Proposed solution

In the first step of the investigations, the mechanical stresses were examined by first identifying possible mechanical stresses. Three types of stress were considered: Pressure, impact and abrasion. Furthermore, the intensity of the damage was considered and defined by means of three intensity classes: low, moderate, high. These classifications then allow an evaluation of the mechanical resistance for the following cases: Compressive stresses with strapping material, impact stresses caused by drop bolts and abrasive stresses due to friction rollers.

In the second step of the investigations, mechanically damaged coating systems are subjected to artificially accelerated ageing in accordance with ISO 20340 [6] to evaluate the remaining corrosion protection effect.



1 *Sample stand with pressure and abrasion samples after storage in the field in the fluctuating water level zone*
2 *Samples after endurance testing*
3 *Load collective under offshore conditions*
4 *The team on site on Helgoland*

Results

On the basis of systematic investigations into the mechanical strength of 15 coating systems, key damage mechanisms due to compressive, impact and abrasion stresses were identified. Using a qualitative evaluation of the coating systems, the compressive damage was categorised according to damage pattern and test force until failure. The impact damage was evaluated on the basis of the visual examination of the plastic deformation (diameter of the damage) and the crack formation. For the abrasion damage, the overall abrasion after 2000 revolutions was evaluated.

In a next step, the remaining corrosion protection effect of the coating systems after compressive, impact and abrasion damage will be evaluated. To this end, accelerated laboratory ageing tests and field tests (fluctuating water level zone, North Sea) are currently being carried out on damaged specimens. The final results are expected in the near future.

Outlook

The results allow us, on the one hand, to introduce new practice-oriented test scenarios for offshore wind turbine coating systems, and on the other hand they show the application potentials of coating materials available on the market for the stresses that can occur during the transport and installation of offshore wind turbines.

Participating partner

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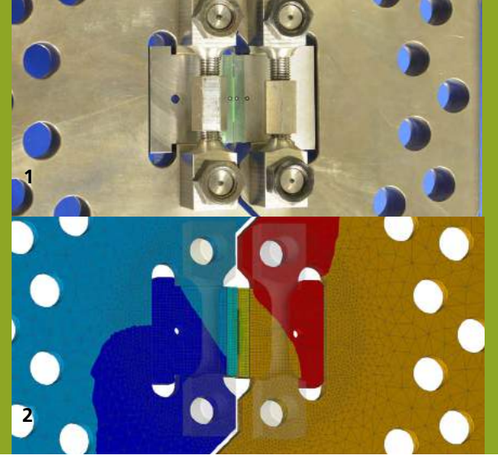
Funding

The project "Partial coating optimisation for transport and assembly of offshore wind turbines" was funded under the Growth Centres New Federal States innovation initiative of the Federal Ministry of Education and Research in line with a resolution of the German Parliament.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Offshore Wind Solutions Mecklenburg Vorpommern



INCREASE IN LOAD-BEARING CAPACITY OF STRUCTURAL BONDINGS WITH FIBRE COMPOSITE JOINTS

Objective

Due to their high specific rigidity and strength, fibre-reinforced plastic (FRP) composites are characteristic materials for lightweight construction and are being increasingly used in sectors such as wind energy, car manufacturing and shipbuilding. Not only the right choice of material, but also an optimum joining technique are necessary in order to manufacture a product following a holistic lightweight construction philosophy. For FRP composite and multi-material joints, the adhesive bonding technology is the optimum joining method, because due to the extensive area on which the forces are exerted, the FRP composite can be perfectly integrated into the material structure. While bonded joints with metallic joint parts, fractures in the adhesive layer or inadequate adhesion between joint part and adhesive generally limit the joint strength, a complex failure within the joint parts frequently occurs in structural bonded joints with parts of FRP composites. Stress peaks occur at the ends of the overlaps of an adhesive bonded joint which lead to localised cracking, interfibre fractures and delaminations within the structure layers of the FRP composite.
As the adhesion and cohesion potential of the FRP composite bonded joint can therefore not be fully utilised, this problem is frequently overcome in practice by the use of over-dimensioned bonding surfaces and hence also increased volumes of adhesive. The variations in the possible design of an FRP composite with regard to the combination of fibre and matrix and the layer orientation and structure allow the material to be tailored to the intended application. The associated possibilities for optimisation of the FRP composite joint parts for structural bonded joints with higher load-bearing capacity are currently still more or less unexplored and form the basis for the "OptiBondFRP" research project.

Approach

With the aim of optimising fibre composite parts for adhesive bonded joining, and hence of increasing the load-bearing strength of bonded joints with FRP composites, various parameters of the FRP composite materials were systematically varied. During the project, material-related parameters such as the weight per unit area of the fibre intermediates (prepregs) and the counts of the fibre bundles, various fibre architectures and matrix systems, design parameters such as the orientation of the surface layers near the adhesive layer and the lay-up sequences of the individual layers, and production-related aspects such as the influence of the fibre volume and pore content were considered. The development of a modified testing method using numerical computations for determining the strength of FRP composite bonded joints formed the basis for the investigation of the above parameters in experimental trials. On the basis of the test results obtained, optimised joint part design options were then derived through a qualitative and quantitative evaluation of the examined parameters.

1 and 2 *Tensile shear test on bonded GFRP laminates with a modified Arcan testing device - experimental trial configuration ad numerical computations*

Results

In the experimental studies carried out we were able to prove that various joint part-related parameters of FRP composites have a direct influence on the load-bearing strength of bonded structural FRP composite joints. The results of the quasi-static tensile shear tests on a bending stiff sample geometry show that with a fibre layer close to the bonding surface in a 0° and 45° orientation to the load direction, practically identical composite strength could be achieved, despite differing failure behaviours. While samples with a 0° top layer exhibit a mixed fracture of cohesive adhesive failure and a matrix failure near the edges in the uppermost resin coating layer, tearing off of the uppermost layer occurs in samples with a 45° orientation of the fibre layer near the bonding surface. The fracture continues as a delamination down to the load-bearing 0° fibre layer. Compared with a 90° top layer, the joint strength was increased by 24%. The fracture pattern here exhibits a complete tearing off of the uppermost 90° layer due to a fracture of the intermediate fibre and a continuation of the failure down to the load-bearing 0° fibre layer. Designs should therefore avoid a top layer with 90° orientation. A further result of the investigations is that a matrix system should be chosen that offers a high interlaminar shear strength of the fibre composite joint parts and a high elongation at fracture. In the trials, an increase in the joint strength of up to 48% was observed with an improved fibre/matrix adhesion. An increase in the load-bearing strength of the FRP composite joints of 5% was achieved by increasing the fibre volume content.

Furthermore, a fine-layered laminate built-up with low weight per unit area of the individual layers and fine rovings at the border to the adhesive layer is to be recommended. This should be taken into particular consideration for structurally bonded fibre composite parts with varying or overlapping load directions. Looking forward we have to investigate to what extent the results obtained from the quasi-static tensile shear tests can be transferred to other load directions and to the fatigue strength.

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Funding

The IGF project "Increasing the load-bearing strength of adhesive-bonded fibre composite and multi-material joints through optimised design and production of the fibre composite joint materials" of the Research Association for Welding and Related Processes e.V. (DVS) was funded via the AiF as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
DVS FORSCHUNG
aufgrund eines Beschlusses des Deutschen Bundestages

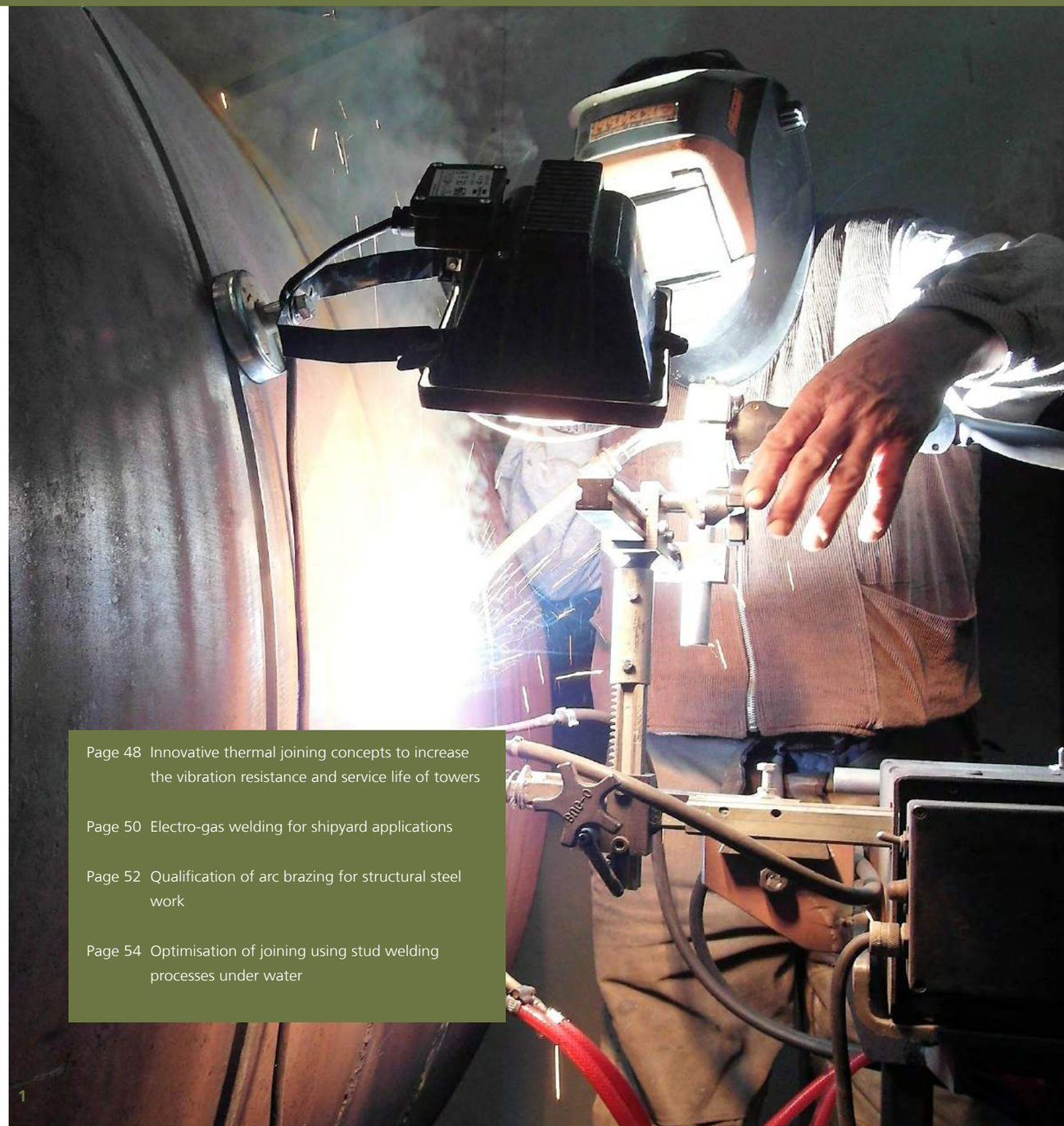
WELDING ENGINEERING

Main research focus and competences

Thermal cutting, coating and joining processes play a central role as value-added and quality-determining manufacturing steps in a large number of production processes. In highly industrialised branches, welded joints and welding processes, in particular, have to satisfy constantly growing and changing demands with respect to cost-effectiveness, flexibility and quality. These include, for example, high-quality processing of modern materials with often high demands on the mechanical and technological properties with consistent process reliability, the assurance of the part integrity of welded components of innovative lightweight steel constructions subject to high static and cyclic loads, increases in the cost-effectiveness of welding processes through modern automation solutions, and the introduction of highly productive welding methods to increase competitiveness as an answer to the growing pressure of costs in globalised markets.

In order to find long-term and sustainable solutions to the resulting technological and economic challenges, the Welding Engineering working group.
of the Fraunhofer IGP is continuously engaged in innovative research and development work on current and future issues from the fields of shipbuilding, structural steel work, onshore and offshore wind energy. The goal is always a holistic evaluation of technological, metallurgical and design aspects of the respective welding applications within the value-added chain.

The combination of innovative analysis methods with modern welding equipment together with standardised and accredited testing technology ensure a flexible and holistic approach to current issues within the scope of public sector and private research projects.



1 *Electric welding process on the pipe*

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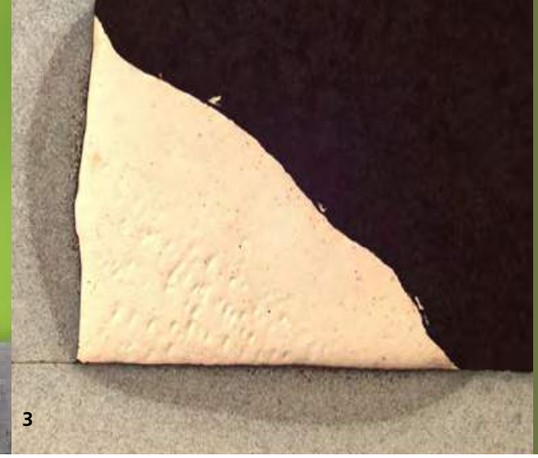

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INNOVATIVE THERMAL JOINING CONCEPTS TO INCREASE THE VIBRATION RESISTANCE AND SERVICE LIFE OF TOWERS

Motivation

During the course of the steady expansion of renewable energies, there is a trend towards ever larger hub heights of wind turbines. This is essentially attributable to a steady rise in output with increasing hub heights due to constant winds at greater heights with increasing speed and at the same time declining turbulence. Modern control concepts for the turbines prevent critical vibration-related resonance of the construction, and thus also permit a theoretical reduction in the sheet steel thicknesses in the tower in line with the lightweight design objective. The towers that are subject to high dynamic loads are predominantly built as formed and welded constructions.

The welded joints and details as metallurgical (e.g. residual welding stresses, micro cracks, unfavourable joint morphologies) and geometric notches (e.g. prevention of expansion due to weld reinforcements) with the associated stress peaks represent typical starting points for fatigue cracks under cyclic loading and have to be compensated during the dimensioning and design by the use of thicker materials or greater tower plate thicknesses, immensely reducing the resource-conserving lightweight construction potentials. In addition to the load-transmitting longitudinal and transverse welds, welded "secondary attachments" in the tower which serve as brackets for e.g. stairs and cable guides and that are not themselves subjected to cyclic loading represent details with an extreme notching effect. These consequently reduce the service life of the construction as a whole, or have a significant influence on the design. The existing measures to reduce this notching effect focus on a reduction of the geometric notching effect (e.g. regrinding of the seam) or metallurgical notching effect (e.g. reduction of unfavourable residual welding stresses by stress-relief annealing or by exerting compressive residual stresses) and generally require extensive reworking. For a sustainable reduction of the plate thickness in line with the lightweight design objective for steel tube towers of wind turbines it is therefore necessary to reduce the notching effect through effective and inexpensive measures directly during the necessary welding and joining processes.

Solution

Innovative joining concepts are being investigated which substitute the conventional welding process in order to reduce the metallurgical and geometric notching effect of welded details while at the same time reducing the amount of necessary reworking. In order to achieve this, not only the conventional drawn arc stud welding process but also magnetic field stud welding with greatly reduced heat input in relation to comparable electric arc welding processes are being qualified for the welding operation. During magnetic field stud welding, the arc is deflected magnetically and the base material is uniformly melted. As a result, the thermal load on the part and the resulting negative thermal effects of the welding process on the fatigue strength can be greatly reduced. As no continuous weld is required for attachment of the stud, the welding time is also reduced compared with the conventional welding process.

A further innovative approach looks at the substitution of gas metal arc welding for attachments by MSG arc brazing using copper-based solders. A substance-to-substance bond is created here by diffusion processes and cohesion forces, but by contrast with the welding process the base material is not melted. The static strength properties are comparable with those of welded joints. For this joining technique that is very similar to the welding process, far less energy is required so that the thermal load on the construction is greatly reduced. Due to the different material characteristics of the copper-based solder compared with steel, the prevention of expansion under cyclic loading of the attachment is also considerably reduced, resulting in lower stress peaks and a significantly higher fatigue strength. No additional reworking or modifications to the production process are necessary.

Benefits and results

The substitution of conventional welding processes with magnetic field stud welding or electric arc brazing for secondary attachments results in an increase in the reference value for the fatigue strength of 40%. Assuming the normal load situations for wind turbines, this corresponds to an increase in the service life of approx. 540% without any additional work for post-weld treatment or modifications to the production process. The resulting safety margin in the dimensioning and design with respect to the fatigue strength can at the same time be utilised in the saving material as part of lightweight construction or innovative tower concepts.

1 *Attachments in a steel tube tower of a wind turbine*
2 *Macrosection of a drawn arc weld*
3 *Microsection of a gas metal arc brazed fillet weld*

Participating partners

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Funding

The project "Holistic resource-efficient tower concept for wind turbines with large hub heights for onshore low-wind locations (GreT)" of Project Management Jülich (PtJ) is being funded by the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
PtJ Projektträger Jülich Forschungszentrum Jülich

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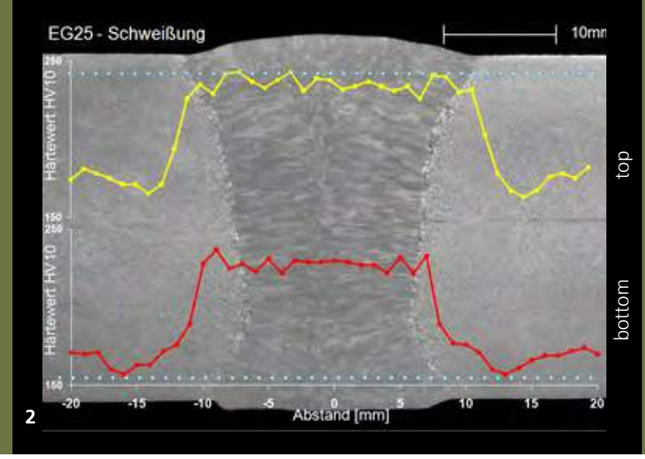


2

ELECTRO-GAS WELDING FOR SHIPYARD APPLICATIONS

Status quo

The strength of the German shipbuilding market lies in the construction of complex ship types, such as deep-sea vessels or river cruise ships. Considering the design of the ships, the significance of welding as the most important joining and production step becomes immediately clear: Plates are reinforced with welded profiles and then welded together to form panels, sections and blocks. Only after the time-consuming final assembly of the hull in the dry dock can the outfitting of the cruise ships outside the dry dock start. The dry dock thus represents the bottleneck in the production chain.

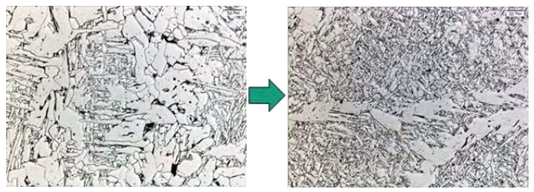
During final assembly, the demanding and time-intensive welding of vertical-up seams on the heavy plates of the hull skin is indispensable. During section and block construction, too, out-of-position up-welding has to be carried out. Normally such welding is carried out manually using the gas-shielded welding (MSG welding) process. An alternative here is electro-gas welding as a fully automated MSG high-performance welding process for vertical butt joints that offers considerable savings in time during production. Particularly in Asian shipyards, this process is used for vertical-up welding. Although the use of electro-gas welding in German shipbuilding is historically documented, there are no longer any shipyard-related applications, and only very few empirical values using outdated technologies. The study of the technological and material-specific suitability of electro-gas welding for modern European shipbuilding is intended to identify possibilities for increasing the cost-effectiveness of shipyard applications.

Approach

Extensive welding trials allowed more detailed technological and material-specific know-how to be generated about the welding process and the properties of joints produced by electro-gas welding. In order to observe the given mechanical and technological properties in shipbuilding, despite the high energy input per unit of length of the process that tends to degrade the properties of the base materials, a special weld filler material was developed specially tailored to the process. At the same time, a requirement catalogue for the normal production difficulties occurring in the shipyard, such as dimensional deviations and tolerances in order to also take these into consideration in the experiments and to guarantee the transferability of the trial results to the situation in practice:

Results

Electro-gas welding allows a drastic reduction in the production time for the ship's hull thanks to single-pass fully automated MSG high-performance welding of vertical-up seams. The reduced non-productive times (i.e. simpler seam preparation, grinding after every pass during manual MSG welding), the reduced distortion of the welded plates, the simplicity of the process, the reproducibility of the welding results and the reduced strain on the welding personnel are the main benefits of electro-gas welding. The necessary know-how for the practical use of the process in the shipyard was gained during the project. Using a weld filler material from ESAB developed on the basis of metallurgical studies at the Fraunhofer IGP, it was also possible to achieve the demanded mechanical and technological properties of the welded joints. A European plant engineering company was also found for the production of the necessary equipment with Merkle GmbH. Both plant engineering and welding technology were validated under shipyard conditions, so that the method has since been integrated into the production process of the project partner, MEYER WERFT, at the Papenburg and Rostock sites. Approval and training are thereby being accompanied by the Fraunhofer IG



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1 *Trail welding at the MEYER WERFT*
2 *Grain refinement in the weld metal achieved by alloy optimisation*
3 *Macrosection and hardness profile of a single-pass electro-gas welded butt joint*

Participating partners

ESAB Welding & Cutting GmbH, Langenfeld; Merkle Schweißanlagen-Technik GmbH, Kötz; MEYER WERFT GmbH & Co. KG, Papenburg

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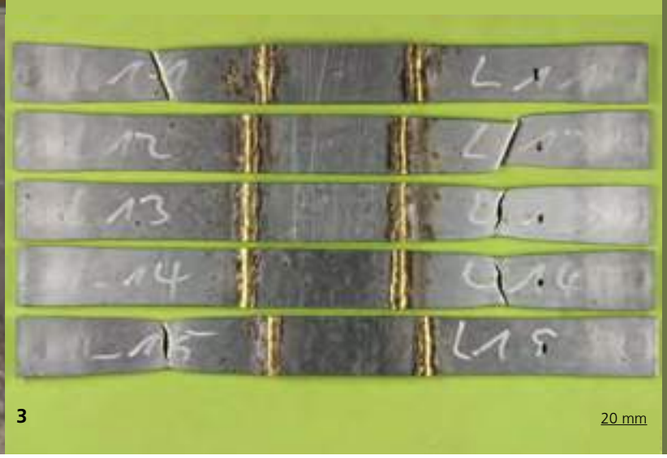

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20 mm

QUALIFICATION OF ARC BRAZING FOR STRUCTURAL STEEL WORK

Challenge

During their lifetime, steel structures are subjected to a wide range of stresses: Both mechanical influences such as static and dynamic loads, as well as environment influences, for example corrosion due to moisture and chemical reactions, or the combination of several factors together place burdens on constructions and require comprehensive measures from manufacturers to safeguard the component integrity.
As a chemical form of stress, corrosion in steel constructions frequently involves immense efforts and costs. A very wide range of parts, from façade elements through to seawater-resistant pipes in shipbuilding, are coated (e.g. galvanised) for corrosion protection reasons. Without removing the corrosion inhibitor coating applied to the base material, however, no high-quality and corrosion-resistant welds can be produced, so that double socket joints (with the welding point "degalvanised") are frequently used during the production of correspondingly corrosion-endangered elements of galvanised raw material, or alternatively the coating is removed, the part is welded and then the corrosion inhibitor has to be applied again. The joining of coated steel structures on the construction site or in the case of repairs also has to be seen as a problem. Here a corrosion-resistant joint is frequently not possible without additional work.
Mechanical influences are taken into consideration in the design calculations for steel structures. But even here, the joints represent the critical areas: The load acting on the structure must not exceed the load that can be withstood by the welded joint. Welded joints reduce the fatigue strength of the complete construction and are the crucial factor for the service life of the structure, particularly with cyclic loads. The resulting design limitations, such as the maximum achievable tower height of wind turbines or the need for unsuitably large wall thicknesses for certain design details, create limits for certain applications or reduce the service life of whole constructions.

Solution

In view of the existing challenges facing welded constructions, the use of electric arc brazing offers a promising option as an alternative to the classic welding process. The process that is already established in the automotive sector (for thin sheet with thicknesses of $t \leq 3$ mm) offers numerous advantages for structural steel work ($t > 3$ mm), but has been barely used to date due to the gaps in know-how concerning the various boundary conditions of the process and an inadequate standardisation situation.
Electric arc brazing offers potentials particularly for the joining of coated parts. Here the lower thermal burden of the brazing process on the base material causes less destruction of the coating, for example in areas alongside the seam or on the inner wall of brazed tubes. The brazed seam (predominantly copper-based solders) itself is very resistant to corrosion and requires no coating after the joining process. In addition, the improved vibration resistance properties of brazed joints with at the same time an adequate static strength expand the design possibilities with the substitution of welded joints with electric arc brazed joints.

1 *Galvanised components: Double tube socket in ship section*
2 *Galvanised electric arc brazed tube with single socket connection*
3 *Electric arc brazed tensile test specimens with base material failure*

Results

During the course of several current projects, extensive trials are being carried out and evaluated on the practical performance of the brazing operation, the static and cyclic load-bearing capacities achievable under various boundary conditions (brazing filler metal, single and multi-pass brazing) and the concrete corrosion behaviour of the joints in order to create a broader know-how base on the process and its fields of application and its limitations. Metallographic investigations will contribute to expanding the know-how on the binding mechanisms of electric arc brazed joints and support the further development of brazing filler metals in line with the needs of the structural steel and shipbuilding markets in cooperation with the project partners. The goal is to establish electric arc brazing alongside welding as a thermal joining process for certain areas of the structural steel and shipbuilding industries. Data for dimensioning principles, performance of the brazing operation, metallurgical improvements and quality assurance will be combined in the two research projects.

Participating partner

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Funding

The IGF project "Influence of production engineering and geometric parameters on the operational reliability of electric arc-welded galvanised steel structures $t > 3$ mm" of the Research Association for Welding and Related Processes e.V. (DVS) was funded via the AiF as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

The IGF project "Use of electric arc brazing for joining attachments to steel structures exposed to high vibrational loads Fatigue" of the Research Association for Steel Applications e.V. (FOSTA) was funded via the AiF as part of the programme to promote the Industrial Community Research and Development (IGF) of the Federal Ministry for Economic Affairs and Energy in line with a resolution of the German Parliament.

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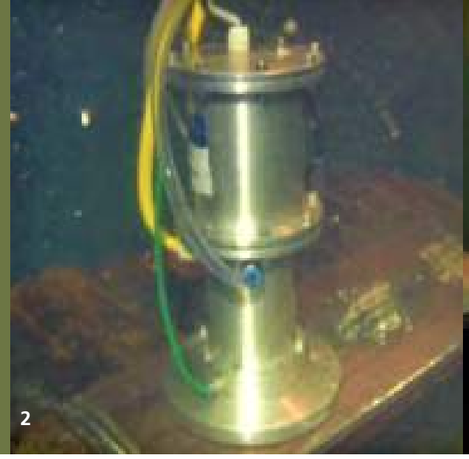
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OPTIMISATION OF JOINING USING STUD WELDING PROCESSES UNDER WATER

Motivation

In hydromechanical steel structures, particularly underwater, the electric arc hand welding process is currently used to produce high-quality substance-to-substance bonds during the repair of structural damage, such as in the case of failures, overloading or due to corrosion. All the measures for maintenance, damage repair and lifetime extension of underwater structures require various practicable attachment elements on steel structures in different depths of water. It is therefore frequently necessary to attach stud-like fasteners quickly and reproducibly to steel structures under water to meet special requirements. Electric arc stud welding with drawn arc has been a proven method for such applications in conventional structural steel work and shipbuilding for over 70 years. As the fully automated welding process requires no special welding skills on the part of the operator, it also offers special benefits for divers during underwater use.
A high welding power and good reproducibility are also characteristics of the process, and therefore substantiate the great potential for underwater applications.

The large stud diameters (threaded studs above M16) used in practice, however, often represent the process limitation for horizontal out-of-position welding in underwater applications. Process modifications are therefore necessary for larger studs. Furthermore, the integrity of all underwater-welded seams is endangered by the introduction of hydrogen as a steel parasite and necessitates special shielding of the seam or welding metallurgical measuring during the welding process.
The goal is to qualify drawn-arc welding of M16 and M24 studs for underwater applications down to 50 m water depth with the corresponding pressure conditions.

Solution

For the use of the stud welding process for underwater applications, a shielding device was developed that should enable high-quality welding in water depths up to 50 m, the typical relevant range for underwater repairs. In order to allow the process to be carried out in much the same way as above water, a local habitat has to be created so that the welding process is carried out "semi-wet". The ambient medium is thereby removed from the welding area and the weld point is freed of residual moisture.

Furthermore, process modifications through adapted parameters and material alterations to the ceramic rings are necessary. The process is analysed by means of high-frequency welding parameter analyses and determination of the hydrogen introduced during the process, and in particular interference influences caused by residual moisture are qualified. The effectiveness of the respective modifications could be confirmed here. In line with the quality demands for electric arc stud welding, visual inspections, mechanical and technological studies of the strength and deformation capacity under quasi-static and cyclic loading and metallographic studies were carried out for qualification of the process. In order to carry out the welding with a defined water depth, the hydrostatic value was simulated experimentally in a flooded pressure chamber (IW-UWTH).

1,2 and 3 *Practical and handling test of the technology for semi-wet underwater stud welding performed manually by the diver*

Results

During the current project "Optimisation of the load-bearing capacity of large-dimension underwater stud welding joints for repair and maintenance measures", a stud welding technology with additional shielding technique was developed for the welding of practicable attachment elements in underwater applications that permits a reproducible semi-wet welding operation under local atmospheric conditions. The equipment has been developed and tested both experimentally and by divers in practice.

In the accompanying studies into semi-wet welding of large-diameter studs, high-quality welds were performed with large stud diameters (M16/M24) in flat and horizontal position. Process instabilities due to residual ring moisture were compensated by a modification of the ceramic ring and the diffusible hydrogen introduced during the process was significantly reduced. The investigations into the process behaviour and joint characterisations were performed on underwater welding specimens. The load-bearing capacity of the stud welds planned for maintenance and repair measures was significantly improved and the practical feasibility was demonstrated.

Participating partners

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Funding

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AUTOMATION ENGINEERING

Main research focus and competences

Automation plays a central role in increasing companies' competitiveness on the global market, also in the context of Industry 4.0. Particularly during the production of large structures, the challenges for the process automation derive from the large workpiece dimensions and weights in combination with large production tolerances of the intermediates.

Our experts are therefore working also on the subject of autonomous programming. Regarding small batch sizes during the production of large structures, efficient programming is eminently important. Our autonomous robot programming is already being successful employed in first applications in the maritime industry. It is based on the evaluation of 3D sensor data or a CAD/CAM link, depending on the particular application.
Furthermore, the Automation Engineering team at the Fraunhofer IGP is also developing new processes and methods for expanding robot-aided manufacturing in order to meet the ever growing demands on quality and cost-effectiveness. Our goal is to introduce and establish robot systems in areas of industry that until now have been unable or only partially able to benefit from this technology.

Particularly in the production of large structures, the demands on the handling technology often exceed the performance capabilities of the systems available on the market. A further core competence is therefore the development, construction and integration of innovative robot technique for use in XXL production. It is our goal to design existing and planned production lines in such a way that they can best meet the demands on quality, reliability and resource efficiency, while still observing the economic constraints.

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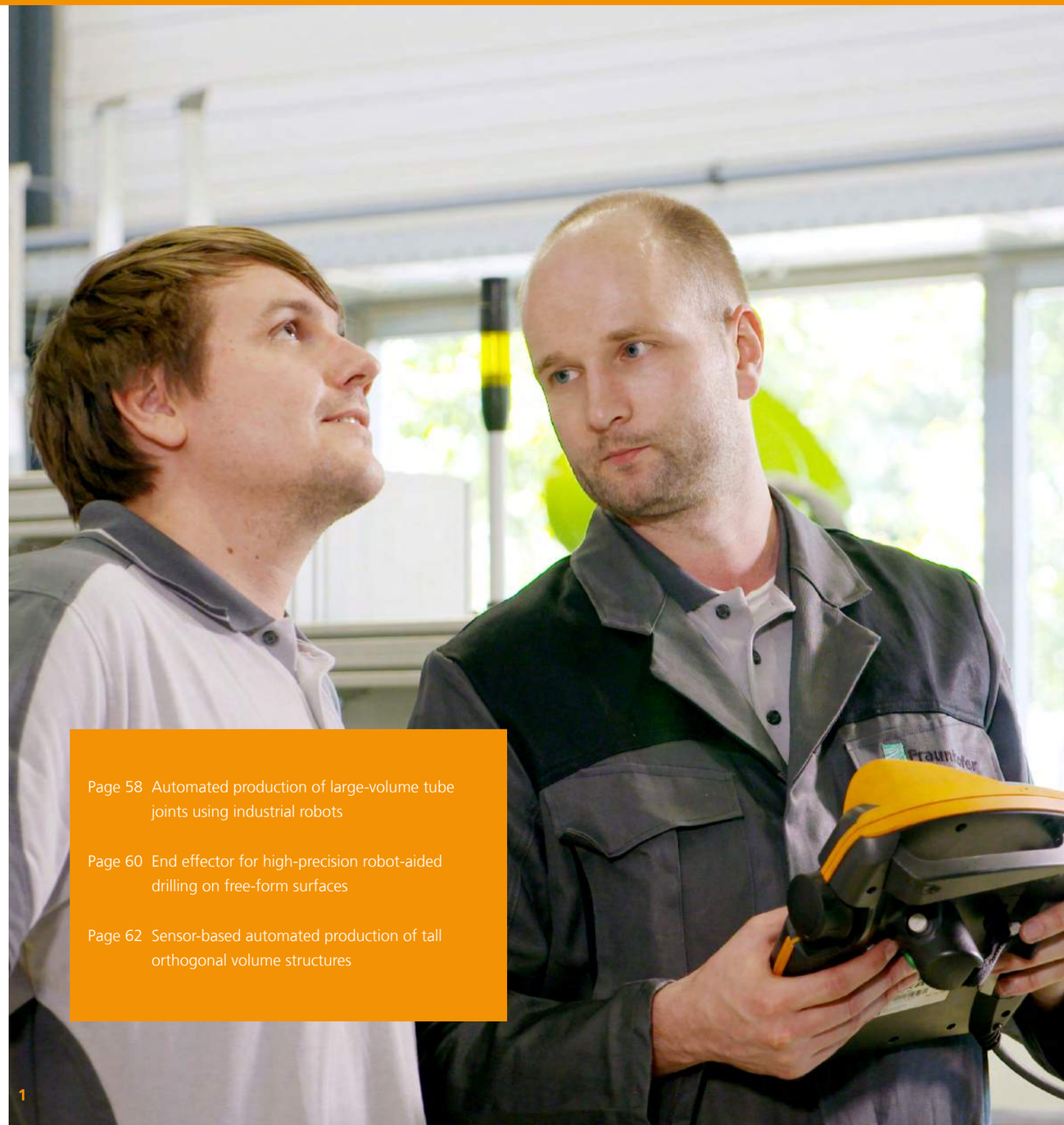

1 *Sebastian Rieck and Sascha Lauer operating the equipment in the laboratory*

Page 58 Automated production of large-volume tube joints using industrial robots

Page 60 End effector for high-precision robot-aided drilling on free-form surfaces

Page 62 Sensor-based automated production of tall orthogonal volume structures

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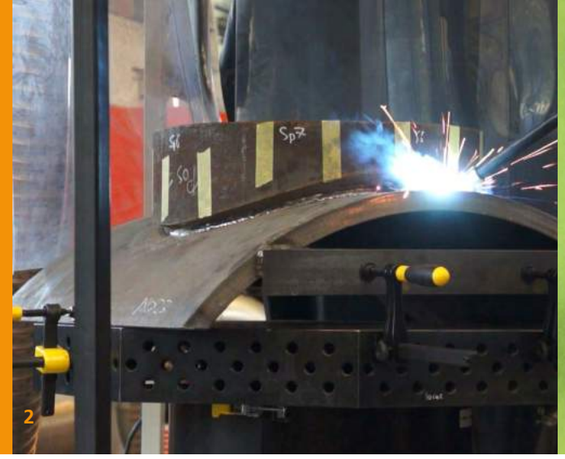
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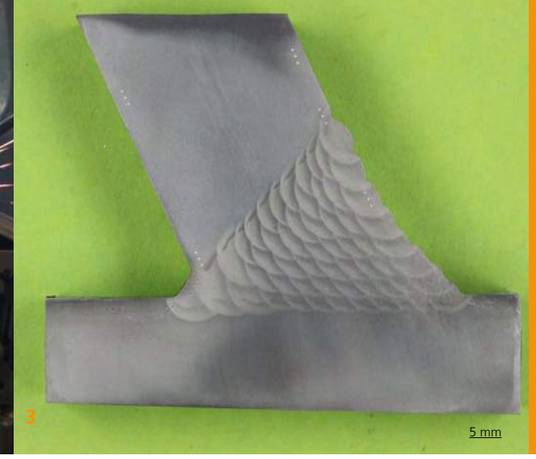

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AUTOMATED PRODUCTION OF LARGE-VOLUME TUBE JOINTS USING INDUSTRIAL ROBOTS

Objective

The exploitation of offshore wind energy is being constantly advanced by the turnaround in energy policy. The foundations for wind turbines and converter platforms are frequently built as lattice structures, and hence as welded constructions. The level of mechanisation in the foundation structure production varies widely. While butt-jointed tube sections are joined in a fully automated process, tube joints are joined manually. An increase in the level of mechanisation and the use of high-performance welding processes in the area of tube joint production offer an increase in productivity and the establishment of reproducible production processes.
Problems in the mechanisation of the production are the wide variety of the parts, the production tolerances of the semi-finished products, the handling of high workpiece weights and the large working space necessary for the use of conventional manipulators, such as a portal system in combination with buckling-arm robots.
The demand profile for the system development therefore includes a minimisation of the system footprint, the avoidance of complicated workpiece handling, sensor-based robot path planning, a high welding speed and the compliance with the demands on weld quality and the mechanical and technological properties.

Solution

In line with this demand profile, a concept for an orbital welding system was developed in which a carrier manipulator is firmly fastened to the workpiece by means of a clamping mechanism; the kinematics of the carrier manipulator are adapted to the geometric form of the workpiece. The small robots at the ends of the kinematic chain are guided along close to the joint by the carrier manipulator. The media and energy supply and the control come from an infinitely rotatable supply platform positioned above the carrier manipulator. This supply platform can be fixed or mobile.
This concept allows efficient use of the workspace and hence a compact design by comparison with conventional multi-axis portal solutions. Infinite movement of the robots, and hence continuous welding, is possible with minimum demands on the reach and load-bearing capacity of the welding robots. The modular system design permits flexible integration into existing production lines.
A concept was developed for the programming of the movement sequences that includes the measurement of the seam geometry, the planning of the layer structure and the actual welding of the filler beads. Prior to the welding process, the joint geometry (seam preparation) is measured using a laser triangulation sensor. The measurement results are used for both the path planning of the welding robot and for the parameterisation of the process.

1 *Positioning of the robot using the external axes along the weld seam*
2 *Welding of a pipe joint on the test stand*
3 *Macrosection of the robot-aided test weldings*

Result

With the development, construction and commissioning of the orbital welding system, an innovative kinematics for the intended application was created. As the concept requires out-of-position welding, the process capability of high-performance welding methods was tested for this application. The metal/active gas welding system employed allows a high overall rate of deposition, and this leads to drastically reduced production times. An AIP (Approval in Principle) from the classification society DNV-GL has been obtained for the system and the welding process.

The automated tube joint production leads to an improvement in the weld seam quality and ensures a reproducible process result. The automation of the process also results in a significant increase in productivity and a considerable improvement in the working conditions by comparison with manual production. The spatially flexible system concept and the out-of-position welding minimises the laborious and cost-intensive manipulation of the tube joints. The modular system configuration also enables the plant to be adapted to different tube diameters, tube lengths and wall thicknesses.

Outlook

The goal of the further developments is, in particular, to automate the whole process of tube joint production. To this end, existing solutions in the field of collar cutting (including weld seam preparation) and the high-precision positioning and alignment of the main tube to the collar have to be developed further. The individual production steps can subsequently linked to form a production line. For the welding process, algorithms for the extension of the system to surface layer welding have to be developed.

Participating partners

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Funding

The project “Automated production of large to very large pipe joints” was funded with grants from the European Regional Development Fund (ERDF). It is being supervised in accordance with the Guidelines for the Promotion of Research, Development and Innovation of the Ministry of Economic Affairs, Building, and Tourism Mecklenburg-Western Pomerania by the project manager, the Technology Advisory Institute (TBI).

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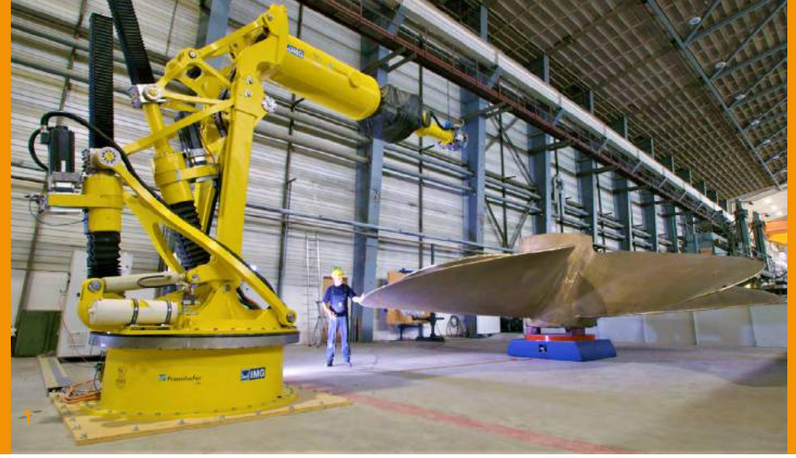

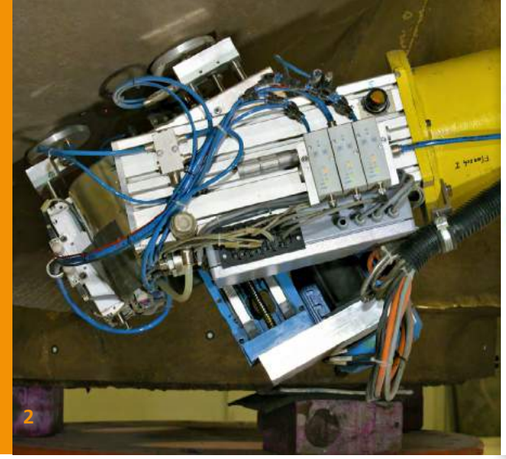

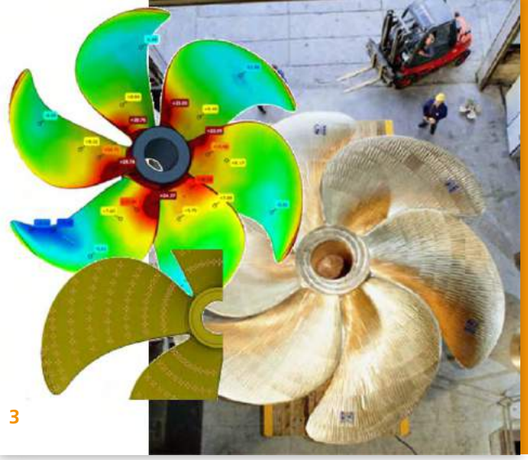

END EFFECTOR FOR HIGH-PRECISION ROBOT-AIDED DRILLING ON FREE-FORM SURFACES

Motivation

The Mecklenburger Metallguss GmbH is regarded as a specialist for the production of ship propellers. These propellers have diameters up to 11.6 m and are adapted to the ship, the engine and the specific application profile. The machining of the cast blanks necessary during production is performed at MMG by manually guided grinding using a hydraulic manipulator. As a reference for the machine operator as to how much material has to be removed, the blanks have a network of blind holes whose bottom represents the nominal surface of the ship propeller. The positions and depths of these holes have to be highly precise in order that the dimensional accuracy and ultimately the efficiency of the propellers are ensured. To date, the production of the up to 1,000 holes was a completely manual process.
The goal of the project on the one hand was to automate this drilling process in order to achieve an increase in quality by avoiding process faults, and on the other hand to significantly improve the working conditions in the production shop by eliminating the manual drilling.

Approach

In order to solve this task, a drilling application was created using a large robot developed at the Fraunhofer IGP. Thanks to its dimensions and the resulting large available workspace, this robot system is predestined for this application. The created application combines the following technologies and processes:

A laser tracker is used as an external position encoder in order to increase the accuracy. This permits both static overriding of individual points and absolutely precise path following in real-time. CAD data of the planned propeller and measurement data on the actual geometry of the propeller blank that are provided by the foundry for each workpiece to be machined serve as the basis for the referencing of the workpiece and the robot using the laser tracker. They are used to create an automatic offline path plan with alignment aid for the propeller. This alignment aid assists the operator in positioning the workpiece relative to the robot using a manually controller rotary table by visualising the optimum workpiece position through laser projection. The goal is to maximise the number of holes that can be drilled with one program run.
A robot system with serial kinematics, particularly in the dimensions involved in this application, has a comparatively low rigidity and therefore has only limited suitability for the machining of metallic workpieces. A further key aspect was therefore the development of a drilling tool that compensates this disadvantage and supports the robot system to such an extent that the demanded precision can be achieved. This tool allows both the fixing of the end effector to the workpiece by means of vacuum grippers to prevent any possible drifting during the drilling process, and also the clamping of the robot against the workpiece to compensate the comparatively low robot rigidity. In addition, a sensor-aided measurement of the drill penetration depth and its surface normality was performed during the drilling operation for the purpose of process optimisation.

1 *IGP large robot on the test bed at Mecklenburger Metallguss GmbH*
2 *Drilling position on the underside of a propeller*
3 *Referencing of the workpiece and the robot by laser tracker on the basis of the CAD data of the design propeller and the measurement data on the actual geometry of the propeller blank*

Result

The drilling application developed provides an innovative process for drilling holes with very great precision with respect to position and depth in any curved surfaces. The number of holes and the geometry of the workpieces are thereby more or less randomly scalable within the framework of the available workspace. Furthermore, the system is effectively independent of the rigidity and absolute precision of the robot used thanks to the extended range of sensors, and thus allows holes to be drilled even in the edge of the ship propeller blade. Occupational health & safety and ergonomics for the worker who previously had to carry out the work manually have also been considerably improved. The quality of the holes was significantly increased by eliminating the reading and drilling depth errors.

Outlok

Following the successful conclusion of the project, we are currently working on the automation of a further step in the production process of large propellers. Manually guided grinding using a hydraulic manipulator will be replaced by a contact force-controlled grinding for production of a defined surface finish on cast parts.

Project partner

Mecklenburger Metallguss GmbH, Waren

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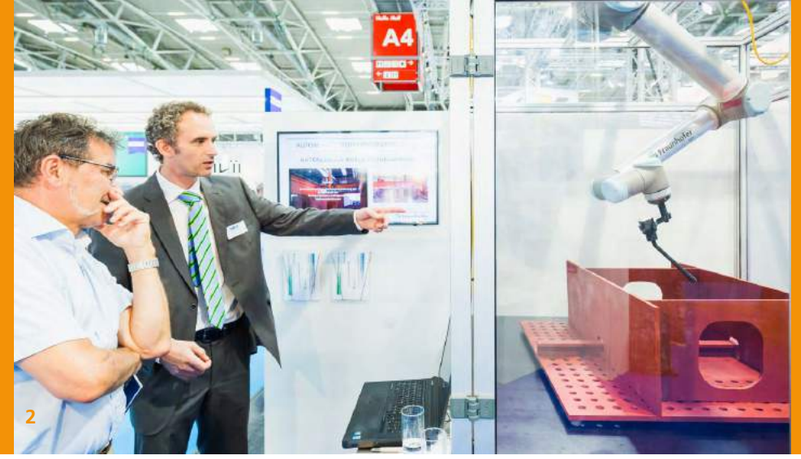

2

SENSOR-BASED AUTOMATED PRODUCTION OF TALL ORTHOGONAL VOLUME STRUCTURES

Status quo

The production conditions in shipbuilding and in the field of offshore constructions are characterised by small quantities, large dimensions of the parts and assemblies and the associated large production and assembly tolerances. One area of shipbuilding in which welding robots are already used, despite these qualifications, is the production of orthogonal volume structures. At present, offline programming systems are predominantly used here for programming of the welding robots where CAD data serve as the basis for the generation of the program. In practice, however, the available systems exhibit a number of significant disadvantages that hinder the use of the robots in production.
The programming of the robots using conventional methods, for example, often proves to be unprofitable when it comes to one-off production. The use of the offline programming systems still makes high demands on the quality of the required CAD data. Furthermore, the program generation in the work scheduling department with a long lead time prior to the production makes the process inflexible for design or technological modifications. In addition, the robot programs often have to be modified in the production shop due to the prevailing part position and the production and assembly tolerances.

Assignment

A process for the programming of the welding robots was developed which, based on 3D sensor data of the prevailing volume structure, generates the required robot programs fully automatically. During the development of the methods for automatic processing of the sensor data, particular attention was paid to the ruggedness of the respective processes. Against this background, a multi-stage segmentation and classification method was developed that allows simplified regular geometric descriptions of the individual parts to be derived from the overall point cloud of a box and to arrange these in a hierarchical structure. Finally the seams to be welded are determined from these data and their parameters are defined.

Using a developed post-processor, the recognised work orders are then converted into a collision-free, machine-specific robot program and transferred to the respective robot controller for execution. The embedding of the path planning into the production process reduces the computing time required for their methods. Furthermore, the time required for each collision test is reduced by primitive approximation. Here objects are replaced by circumscribed geometric volumes, such as capsules or cubes, in order to accelerate the distance calculation by using simpler algorithms and to achieve a high processing speed.

1 *Automated welding of a seam within the mock-up structure*
2 *Scan of the volume structure using a swivelling 3D scanner mounted on the side of the linear axis*

Benefits

Characteristic of the developed system is that the robot programming is integrated into the production process and is thereby independent of any technological technological preliminary work and engineering data. It thus enables a reduction in the work involved in generating the robot programs and an increase in productivity on the production line. The suitability of sensor-based robot programming for tall orthogonal volume structures was demonstrated by integrating the system into an existing production line at Nordic Yards in Warnemünde. The stored robot and system parameters can be modified, allowing the system to be flexibly employed with other industrial robot types and plant specifications.

Outlook

The focus of future developments is on expanding the field of application of the system by extending the range of recognisable part and weld seam types for a broad spectrum of volume structures. A further research project aims to overcome the limitation to orthogonal structures.

Participating partners

Ingenieurtechnik und Maschinenbau GmbH, Rostock; Hensel Elektronik GmbH, Rostock; Nordic Yards, Wismar; University of Rostock, Rostock

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Funding

The project “Sensor-based robot programming for automated production of tall orthogonal volume structures” was funded as part of the “InnoProfile Transfer” programme under the new Federal state innovation initiative “Entrepreneurial Regions” of the Federal Ministry of Education and Research in line with a resolution of the German Parliament.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

WACHSTUMSKERNE
UNTERNEHMEN REGION
Die BMBF-Innovationsinitiative Neue Länder

MEASURING OF LARGE STRUCTURES

Main research focus and competences

Together with its industrial partners, the "Measuring of Large Structures" team develops measurement and quality assurance concepts. A comprehensively equipped measurement laboratory for stationary and mobile applications and a multi-disciplinary team form the basis for innovative solutions.

Current analysis and evaluation methods from science and research are employed to study the key topics of geometric quality control and the control of production processes, provision of the current state as a planning basis, online programming of robots and building condition monitoring as a basis for simulation, processing, analysis and modelling (reverse engineering) of point clouds, modified software development for data evaluation and the analysis and automation of measurement processes.

With a vast range of services, we offer our clients comprehensive solutions in the fields of reverse engineering, quality control, 3D tolerance analyses, creation of the basis for planning and simulation based on measured data, manufacturer-independent analysis, consultation and planning of measuring and testing processes, development of methods for control of production processes, precision manufacturing in the assembly process, building condition monitoring and in modified software development for data evaluation and automation of measurement processes.

1 *Lars Bretthauer during surveying with a structured light 3D scanner*

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APPROACH TOWARDS INTELLIGENT AND ADAPTIVE PRODUCTION OF LIFTS

Background

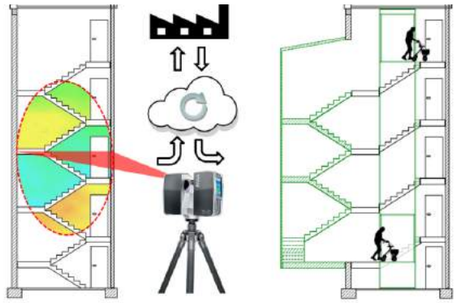
Barrier-free and senior-friendly conversion of existing buildings represents a major challenge for operators and owners of real estate. The subsequent installation of lift systems involves lengthy measurement and assembly processes and hinders access to the premises for the tenants. Until now, lifts have been retrofitted on existing buildings by means of an annex on the outside of the building. As the annex adjoins the stairwell, a handrail still has to be overcome in order to reach the apartments. Access to the cellar is also not possible with a lift fitted to the outside of the building. In the Lift 4.0 project, solutions are being developed to enable a completely barrier-free lift installation with significantly reduced installation time.

Proposed solution

Complete barrier-free access is achieved by installing a lift inside the building. For this, stairwell side is replaced by the lift shaft and reconstructed in a modular external annex. The installation and modification work is supported by a digital planning basis. Based on 3D measurement data, the planning basis provides a uniform flow of information for all the trades involved in the building. An application-specific measurement and evaluation strategy is required for creating the planning basis using laser scanners.
In the first step of the study, the measurement uncertainty of different laser scanners was first investigated. Particular attention was paid to the development of a measurement system that takes the vertical tolerance specifications into consideration, as the lift shaft – and hence also the planning basis – has to run perpendicularly. The assessment of the laser scanners was followed by the establishment of a reference field for analysis of different measurement and evaluation approaches. The results of numerous measurement configurations and evaluation variants were compared with the reference field surveyed with the superordinate precision in order to identify the optimum strategy for the measurement of stairwells. The result of the evaluation is a high-resolution point cloud of the stairwell. Everyone involved in the building project can derive a wide range of measured values, illustrations and simulations from this data set without requiring a further inspection on site.
For further processing, a software prototype was developed with which the geometric parameters for the lift installation can be calculated. The implemented algorithm calculates the maximum possible installation space, as well as the position and orientation of the lift shaft.

1 *Calculated maximum cubage on the basis of the laser scanner data*
2 *Lift installed indoors in an existing building*
3 *Workflow for efficient manufacturing and installation of an indoor lift in existing houses on the basis of as-built planning data*

If the shaft size is smaller than the minimum required size, the software analyses the run of the walls and calculates the necessary modifications. The data form the basis for a 4.0-compatible process chain.



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Results

A measurement and evaluation concept for application-specific analysis of stairwells was developed on the basis of systematic studies. The measurement data obtained are modelled in a digital planning basis and provide a holistic flow of information for the whole duration of the construction phase. On the basis of in-process measurements during production, a concept was identified for efficient implementation of modular construction. The "BIM approach" takes as-built conditions for every measurement object into consideration and ensures optimum use of the construction space. A completely barrier-free lift system can thus be installed with significantly reduced measurement and installation time.

Participating partners

Hochschule Wismar, Wismar; Zurow Bau GmbH, Zurow

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Funding

The joint project "Development of an Industry 4.0-compatible approach for integrated data engineering, intelligent and adaptive production of a lift" is being funded by the Technologie-Beratungs-Institut GmbH.

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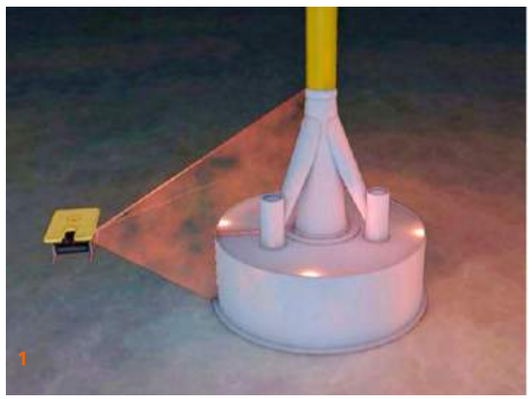
3D MEASUREMENT AND MONITORING OF UNDERWATER STRUCTURES

Objective

The sea today represents an important area for power generation, but also as a supplier of raw materials. Offshore wind turbines, tidal power plants and drilling rigs are constructions that have to be erected partially or completely in water. Such constructions require regular and objective inspection and testing – operations that until today have been possible only visually by divers or acoustically using sonar equipment due to the lack of efficient systems. Due to this there is a need for precise, efficient and preferably automated methods for a regular inspection of the underwater structures. During the course of the project, the laser-based scanner system for 3D inspections developed by the project partner was expanded to include algorithms for quick and reliable data evaluation and integration.



Approach

The focus of the project is on the development of a process for detection of deformations in underwater structures on the basis of scanned 3D point clouds. Underwater laser scanners such as the system developed by the project partner are able to scan the surfaces of underwater structures contact-free and to image them in the form of point clouds. Considering that the large number of interference factors under water, such as the light absorption, the limited visibility or particles suspended in the water, the measurement data has larger measurement uncertainties than for comparable measurements above water. Adapted, sensor-specific filter algorithms and operators were developed for reliable interpretation of the unstructured point clouds. The basis for a deformation analysis is the high-precision recording of the various measuring epochs in an evaluation process adapted to the ambient conditions that runs more or less automatically. The software developed during the "DeepInspect" project analyses the measured point clouds pretty much on site and within a very short time so that any necessary remeasurements can be initiated during or briefly after the original measurements. Also deformations can be detected without time-consuming post-processing. Demands on the evaluation software are fast processing, detection of possible deformations, clarity, ease of operation and simple and clear evaluation results.

1 Concept for inspection of underwater structures using laser scanners

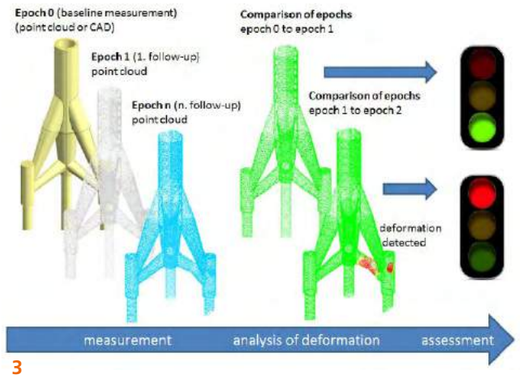
2 Test of an impulse-based underwater laser scanner system with defined test specimens

2 Concept for comparing results from different measuring epochs with one another and with the architecture model

Benefits

On completion of the project, the user will have an evaluation software available that is adapted to the developed measuring system and that takes specific measurement parameters into consideration. The user is thus able to carry out quick and automated deformation analysis of scanned point clouds.

The combination of innovative underwater measuring technologies and partly automated evaluation software will, prospectively allow precise and efficient inspection of underwater structures to be carried out.



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Participating partners

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Funding

WISA - cross-institutional initial research for the development of technologies and products through strategic business-ori-

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GEOMETRIC MEASUREMENT AND DATA EVALUATION OF SHIP SURFACES FOR EFFICIENT COATING PROCESSES

Motivation

In yachtbuilding, the outer visible surfaces are smoothed with a filler in a very laborious manual process before painting. The filler thickness at any point is determined iteratively, so that the coating process is very time-intensive and results in costs running into the millions. Existing methods for controlling the filler work have proved not to be efficient enough for large yachts, as the filler coating during the manual smoothing is modelled on the basis of scanning data. This leads to subjective and insufficiently reproducible results.
The goal of the FINISH joint project is to develop an automated process for controlling the filler work. To this end, enveloping free-form surfaces are derived under optimisation criteria automatically from measurement data. To further accelerate the process, a modified measurement concept adapted to the process requirements is developed.

Proposed solution

A significant acceleration in the data acquisition can only be achieved with a fundamental change in the measurement concept. Until now, 3D object measurement has been performed by static terrestrial laser scanning (s-TLS). For large structures, 50 or more individual measurements are frequently necessary that then have to be referenced and processed. In order to avoid this enormous expenditure of time, the 3D object measurement should instead be carried out kinematically (k-TLS). A laser scanner operating in profile mode travels past the object on a moving platform and is referenced with high precision

2

by a laser tracker. The measurement and design data are then preprocessed by means of an automated data cleansing. Furthermore, function and design elements are identified that are taken into consideration as nominal criteria for the surface generation. In addition, the measured data is analyzed with respect to the contour in order to identify relevant points on the surface of the ships hull.
These points are used to generate an ideal surface finish for the yacht. This is characterised by a minimum filler coat thickness with the sleekest possible surface contours. The template for this is the design data of the yacht whose contours have to be adapted to envelope the surface points, while observing all the criteria.

1 *Finished megayacht*
2 *Kinematic laser scanning for surveying the outer shell of the ship*
3 *Automated derivation of sleek surfaces from laser scanning data*
4 *Quality assurance of surfaces on the basis of optical criteria*

4

The automated differentiation between the cleansed measurement data and the generated ideal surface finish, a filler map is generated that is then used in the following manual production process.

Outlook

The time required for the dynamic surveying of large surfaces such as a ships hull is significantly reduced by the used of the developed measuring system.
The automated cleansing of the measurement data and the subsequent classification reduce the amount of manual work and hence lead to a considerable reduction in time and costs.

The automation of the generation of arithmetically optimised surfaces also reduces the amount of manual work. In addition, the quality criteria to be observed are defined for the first time and are used for evaluation of the results. This allows the quality of surfaces to be assessed under visual aspects for the first time.

Overall it enables the coating process in yachtbuilding to be accelerated. The filler prediction can also be used for the prefabrication of parts for complex areas. In addition, this process provides an objective evaluation of the filler coat and the hull contours. Its application avoids the need for reworking, and hence additional costs.

Participating partners

Dr. Hesse und Partner Ingenieure, Hamburg; Fr. Lürssen Werft GmbH & Co. KG, Bremen; Geodätisches Institut Leibniz Universität Hanover, Hanover; Institut für Fertigungstechnik und Werkzeugmaschinen - Leibniz Universität Hanover, Hanover

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Funding

The “Exact and quick geometry measurement and data evaluation of ship surfaces for efficient coating processes” joint project with the project “New methods for automated model generation” is being funded by the Federal Ministry for Economic Affairs and Energy.

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

2

3D INFORMATION SYSTEM FOR DAMAGE ASSESSMENT OF WIND TURBINE ROTORS DURING OPERATION

Status quo

In view of the technical complexity and the widely varying loads that act on a wind turbine, regular inspections of the installation are necessary in order to be able to guarantee safe and reliable operation. At present, the inspection of wind turbines for damage predominantly involves analogue measuring equipment and photographic documentation. This analogue form of inspection raises the following problems: time-intensive recording of the damage points, high susceptibility to mistakes, lack of reproducibility due to the subjective evaluation of the damage on the basis of photos and poor analysis possibilities due to the shortage of a database.
These deficits mean that a quick and objective inspection is not possible. The demand for the shortest possible standstill of the wind turbine for the inspection can only be met to a limited extent.
The goal of the process innovation was to improve the inspection of both onshore and offshore wind turbines through the use of modern digital measuring equipment and information technologies. In particular the time need for the inspection should be reduced, but with an increased information content.

Solution

In order to implement an improved, more fault-resistant process, the whole inspection process was digitised. For this digitisation, a 3D information system with the following three system components was developed and employed:

1

Mobile inspection system
The system consists of a 3D laser scanner in combination with a mobile terminal for the documentation of existing and new damage that is used by the inspector on site. A measuring system was developed for the practical use of the laser scanner.

Stationary overall inspection system
This system comprises the evaluation software and an interface to the database management system. The overall inspection system allows the positions of the damage in the rotor blade coordinate system to be derived from the recorded laser scanner data, and the distances and angles between structures to be determined. In addition, the inputs by the inspector can be checked and then saved to a database.

Data management system
A database was created for quick and clear storage of inspection data. The integration of the inspection data is greatly simplified by means of a user interface so that no prior knowledge in the use of databases is necessary. The long-term storage of the data and cross-references between table contents allow long-term analyses to be carried out.

1 *Example of a rotor blade*
2 *Point cloud of an inspected rotor blade internal structure*

Results and benefits

As a result, the user has a measuring system available for quick digital analysis of the condition of rotor blade internal structures using laser scanner and software for analysis, documentation and data management of the collected laser scanning data on the inspected damage points.

The digitisation allows a significant acceleration and objective analysis of the inspection process on wind turbine blades. In addition, a consistent digital data flow and the possibility of of spatial geometric evaluation have been created. As the inspection data is related to the planning data, the evaluation of the results provides feedback on the production process. The 3D information system serves here as the basis for long-term analysis of turbine damage.

Participating partners

Tools for composite GmbH, Güstrow

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COMPANY AND PRODUCTION ORGANIZATION

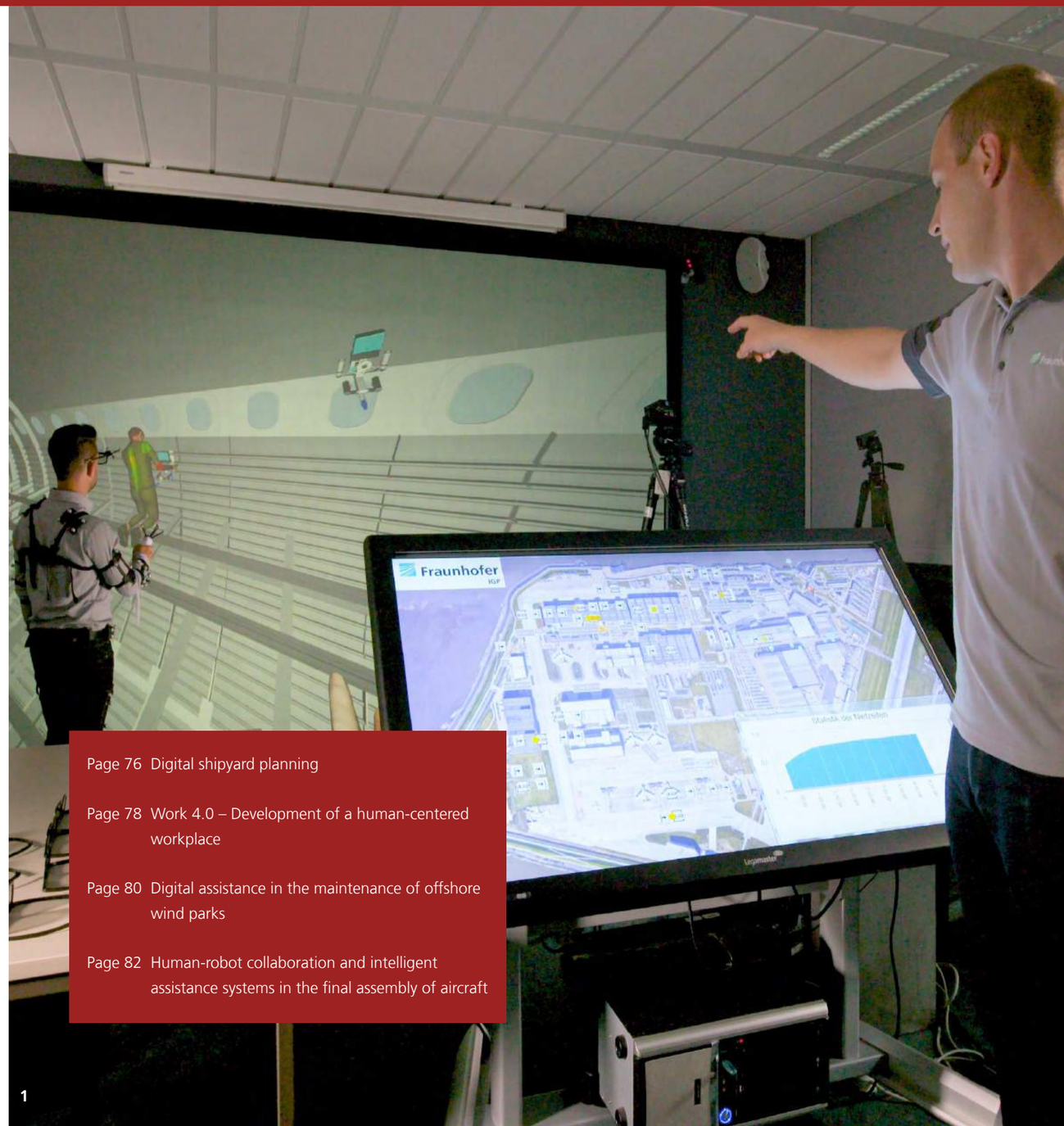
Main research focus and competences

The Company and Production Organisation team of the Fraunhofer IGP develops individual solutions for the structuring and control of production of the future in close cooperation with industrial partners.

In the field of factory and logistics planning innovative methods and tools of the digital factory, such as material flow simulation, 3D-layout planning and robot simulation are employed. These approaches enable to support industrial partners for example in the validation of reorganisational or investment projects.

At shop floor level, the focus is on the development and implementation of individual solutions for the smart factory in the context of Industry 4.0. These include IT-based process data acquisition systems that in combination with the latest tracking technology lead to an increase in transparency on the production process. At the same time, the quick and flexible provision of digital information to the employees is becoming increasingly important. To achieve these goals, assistance systems such as data glasses, tablets and other smart devices are employed.

A further focus of the work is on the area of ergonomic assistance systems. The use of ergonomics simulation and intelligent workplace systems enables assembly processes to be ergonomically correctly and efficiently planned. In addition, innovative production concepts are developed based on the human-robot collaboration.



1 *Florian Beuß and Benjamin Illgen during digital factory planning and ergonomics analysis using virtual reality*

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DIGITAL SHIPYARD PLANNING

Status quo

One-off production in shipbuilding involves repeated new planning. Furthermore, the industry is characterized by complex material flows within the production and logistics, and by extensive interdependencies between the process stages. Moreover, the production planning almost always starts before the completion of engineering work. Further specifics are enormous space requirements, high weights of the products and very long lead times. This massive complexity of the planning work quickly brings static planning tools up against their limits. Due to the unique character of the industry as described above, there are no digital tools that can be used.

Proposed solution

The Fraunhofer IGP approach to the planning and evaluation of production and logistics processes within one or more shipyard sites creates a digital image of all planning-relevant sub-areas based on the tool of the event-discrete material flow simulation. The real starting situation is thus transported into the digital world using the product-process-resource structure. By modelling the shipyard and the ships to be produced, scenario-based dynamic loads on the available resources can be simulated with the production programme. In addition to the production of individual parts and their assembly, the simulation also covers the equipment and logistics of the site and its suppliers. Further key elements implemented in the model are area allocation planning, employee planning (qualitative and quantitative) and shift planning. As a result, the user is provided with statistical evaluations as a reliable basis for the evaluation of the production processes and hence their planning. The findings obtained offer the possibility of evaluating the production plan with respect to plausibility and bottleneck situations. Furthermore, any conceivable measures can be validated with respect to their impact on the system behaviour.

In addition, one approach is to visualise the production processes and the planned scenarios intuitively using virtual reality in order to develop a consistent overall understanding in team-based planning meetings. This should also make changes and their effects comprehensible so that they can be implemented interactively on site. This creates a high-quality planning basis.

1 *Model of a production line for panels*
2 *Digital image of a shipyard*
3 *Interactive and team-based planning process using virtual reality*
4 *2D view of the simulation model*

Results and benefits

The simulation of a shipyard site creates the benefit of an improved and transparent planning basis. Furthermore, the user is able to review set deadlines and, if necessary, to implement various measures to prevent delays. Bottlenecks are recognized in time and can serve as the basis for deriving recommendations for action. In addition, a review of possible measures with respect to their impact can be carried out without representing real risks by implementing a scenario at the site. In the long term, this leads to a reduction in the costs resulting from planning errors. Furthermore, it provides an objective basis for the decision-making process for the production and logistics planning.

The presentation of the planning contents in virtual reality and the associated immersive experience of the planned scenarios and their interactive implementation creates an objective and consistent understanding for the plans among all stakeholders. This sound basis results in a better understanding, greater acceptance and significance streamlining of the planning process.

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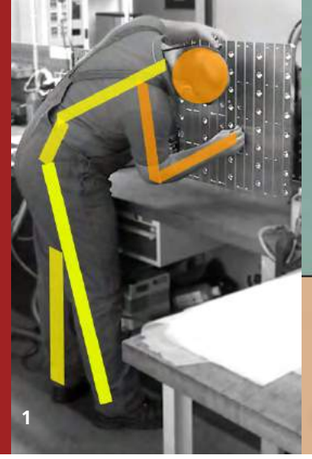

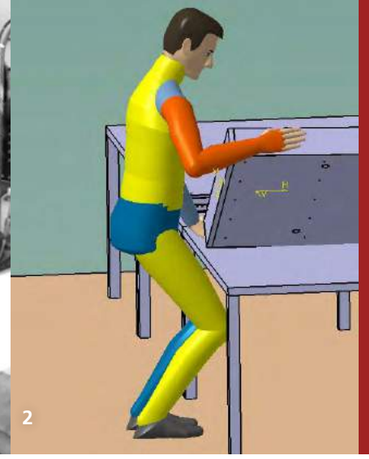

WORK 4.0 – DEVELOPMENT OF A HUMAN-CENTERED WORKPLACE

Motivation

Especially in assembly areas where automation - for example with robots - is not economical, the flexibility of employees is required when solving complex tasks. The ability of the employees to work must therefore be preserved or a decrease of work performance must be prevented. When it comes to working with large and heavy parts in general, conventional workplace systems offer only limited support and avoid ergonomically correct and efficient working practices. These problems formed the motivation for the development of an intelligent workplace system for the assembly of large parts in the context of the Project "ErgoTab".

Proposed solution

Analysis of the status quo
For the development of concrete optimization approaches, holistic analysis processes regarding the assembly activities were carried out at the application partners. To objectify the process images, the results were modeled in a simulation environment. The ergonomics were then evaluated using the Rappid-Upper-Limb-Analysis method. In order to ensure a realistic representation of the movements, these were created with inverse kinematics. The distribution of the risk classes for the current situation showed that a change in the workplaces was essential.

Development of a human-centered workplace

Based on the results of the ergonomics analyses, a kinematics concept was derived, by which the deficient body positions can be compensated. The adjustment of the workstation system is carried out by an automatic control of various drive systems for an ergonomically optimal adjustment. The determination of the correct final positions of the corresponding drives is realized on the basis of a contact-free identification of the component and the physiological conditions of the employee. The flexible adaptation is achieved by a combination of translatory and rotary drives with high reaction capabilities.
During the development phase, the general functionality of the kinematics concept was tested and validated using virtual reality mock-ups. The transfer of employee movements to the virtual scene took place via a marker-based tracking system. Changes to the drives and adjustments to the action areas could thus be implemented quickly.

Implementation of the intelligent workplace system

The workplace system was developed in line with the concept of modularity that allows adaptation to different requirement profiles. The radio-frequency identification (RFID) technology is used for contact-free identification of the various employees, the workpiece and the respective process step.
The identification of the respective part allows conclusions to be drawn on the assembly step, enabling the optimum adjustment of the system to be computed. Using smart devices, the individual drives can be controlled separately, ensuring subsequent and smooth adaptation. Another interface that allows human-machine interaction is a touch screen that displays further information in addition to the various states of the system. Interactive assembly instructions provide visual assistance.

1 and 2 *Transformation of the real assembly movements into a digital simulation environment for evaluation of the ergonomics*
3 *Digital mock-up for evaluation and optimisation of the prototype*
4 *Intelligent workplace system for the assembly of large and heavy parts*

Results

The described workplace system enables the holistic optimization of ergonomics during the assembly. By integrating the kinematics and combining them with an intelligent control system, interpersonal and process-dependent adjustments of the workplace system or the adjustment of the workpiece to the worker are possible. The powerless manipulation of the heavy components and the avoidance of forced postures during assembly minimize the physical strain on the operator.

Outlook

The results of the extensive analyses showed that great optimisation potential exists in the field of workplace systems and the manual assembly of large parts. Due to the complexity of such assembly processes, the workplace systems have to follow a holistic approach to the solution so that rigid structures do not meet these requirements. In the next stages of development, the human-machine interaction, the mechanical assistance and the modular structure have to be advanced.

Participating partners

MiniTec GmbH & Co.KG, Schönenberg; VARIOVAC PS System-Pack GmbH, Zarrentin am Schaalsee; REFA MV GmbH, Rostock; KLH Kältetechnik GmbH, Bad Doberan

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Funding

The project "Development of an intelligent workplace system for the assembly of large components" was funded with grants from the Federal Ministry of Education and Research.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

DIGITAL ASSISTANCE IN THE MAINTENANCE OF OFFSHORE WIND PARKS

Motivation

The growing complexity of components and equipment in offshore wind parks is making ever-increasing demands on the personnel for operation and maintenance. The complexity of the components results in equally complex maintenance processes. Faulty performance of maintenance and repair work has serious economic impacts. The variable boundary conditions in offshore maintenance and repair with respect to the tough environmental conditions, communication infrastructure, occupation health & safety demands and work contents are obstacles to the software and hardware configuration of a flexibly applicable assistance system. Even recurring work is therefore documented on paper and the benefits of digitisation are not utilised.

Proposed solution

A method for application-specific configuration of assistance systems for mobile application in the maintenance of offshore structures was developed as part of the "OWS – Offshore Wind Solutions Mecklenburg-Western Pomerania" growth kernel. The exceptional challenges posed by the tough boundary conditions during offshore operation were taken into consideration by forming reference scenarios from the actual offshore business. The method thus takes into account the various differences in the maintenance and repair work and can offer the optimum basis for the actual system configuration in each case. A configuration tool was developed here that generates suggestions for appropriate hardware specifications and terminal types on the basis of the description of the application scenario and the maintenance or repair work to be carried out. Bilateral, demand-oriented information flows were configured for the link to the underlying data model. Both online and offline operation of the assistance system is thus possible. In order to meet the changing demands of the respective task in hand, various sub-methods of the interaction and data processing were developed as modules that can be incorporated into the assistance system as required. Depending on the user demands, the assistance system can then be controlled either manually or with voice commands as an information aid or documentation tool and integrated into the equipment in the form of a tablet or smart glasses. The interface to a central data model accelerates the flow of information. As a result, the work and the application results can then be evaluated faster onshore to enable the personnel and material requirements for subsequent maintenance and repair work to be planned according to requirements. In addition, the digital recording in the information system creates a digital life-time documentation of every piece of equipment in the wind park.

1 *Application scenario offshore platform*
2 *Digital assistance in the maintenance of offshore wind parks*
3 *Evaluation of the assistance system in the virtual wind park*

Benefits

The functions and structure of the methodology for the application-specific configuration of assistance systems for mobile use in the maintenance of offshore structures allow complex maintenance and repair processes to be carried out faultlessly and create a continuous digital documentation. Workers on site are provided with optimally prepared information, depending on the boundary conditions defined by their tasks, and are guided through the work by digital instructions. The system functions here as an assistant to the worker and supports the processes involved with the scope of functions required. The interface to the central information platform allows the digital life-time documentation of every piece of equipment to be requested and updated during the work, so that the processes related to the maintenance and repair work can be effectively accelerated during the work planning and post-processing.

Outlook

The results of the methodology can be transferred from the offshore wind sector also to other branches of industry, such as industrial plant engineering or the building industry. The methodology provides the necessary basis for digitally imaging not only the maintenance and repair work, but also processes in other life-cycle phases, and for supporting employees with information in carrying out their work under industrial environmental conditions through mobile assistance systems, and for accelerating workflows. The data gained through the feedback collected in the assistance system can also be evaluated and used for further measures. Employed in the field of one-off and small-batch production, such systems can provide an important basis for setting up knowledge databases and for the planning and control of processes. In the next stages of development, the human-machine interaction and the hardware suitability for industrial applications have to be further advanced.

Participating partners

IMAWIS GmbH, Rostock; Krebs Unternehmensgruppe, Hamburg; Neptun Ship Design GmbH, Rostock; ONP Management GmbH, Hamburg; SEAR GmbH, Rostock

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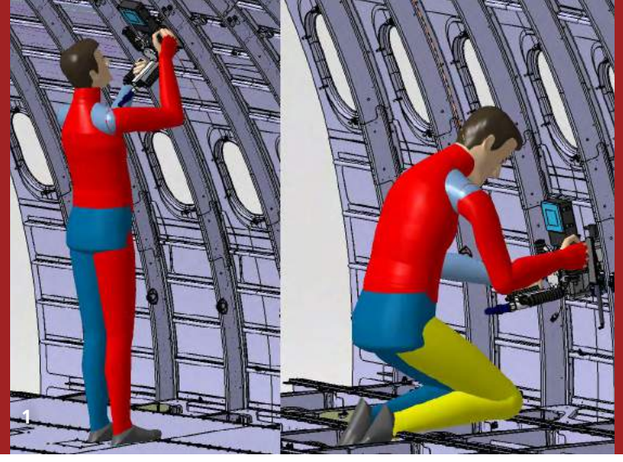
Funding

The project is being funded with grants from the Federal Ministry of Education and Research as part of the growth kernel "OWS – Offshore Wind Solutions Mecklenburg-Western Pomerania".

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

OWS MV Offshore Wind Solutions Mecklenburg Vorpommern



HUMAN-ROBOT COLLABORATION IN THE FINAL ASSEMBLY OF AIRCRAFT

Challenge

The global growth in the transport of people and goods has a direct impact on the demand for narrow-body aircraft. The orders in hand with the single-aisle aircraft manufacturers have reached new heights. As a result, Airbus is planning to increase the production rate of its A320 medium-range aircraft. In addition to an additional final assembly line, new production technologies are also to be introduced to replace the predominantly manual final assembly of the aircraft to date. One task during final assembly is the manual joining of so called stringers of individual sections by stringer couplings using conventional solid rivets. In future, solid punch rivets will be used here that offer a significant reduction in the required process steps and process time. In a cooperation project between Airbus, Tox Pressotechnik and Fraunhofer IGP, the process already known from automotive construction was qualified for use in aircraft construction and intelligent tools for punch-riveting were developed. In view of the high process forces during punching, the tools have a high dead weight so that the manual assembly would result in high physical burdens for the staff during manual handling.

Proposed solution

In order to overcome this problem, an intelligent assistance system was developed on the basis of a collaborating robot system that assists the staff physically and mentally during joining of the stringers and stringer couplings along the aircraft body. Additionaly it allows sustainable quality assurance.

Human-robot collaboration

The human-robot collaboration (HRC) combines the advantages of manual and automated assembly. In the present application, a hand-guided lightweight robot from Universal Robots with a carrying capacity of 10 kg was used to which the riveting tool is attached. In addition, a force-torque sensor (FTS) has been implemented that measures the forces applied by the employee during guidance of the robot. The low force applied by the worker during manual guidance is transformed into a movement of the robot, so that the tool can be moved freely and to the joining positions intuitively and without physical effort.

Integrated operation

The combined robot/riveting tool system is controlled via an integrated control unit. For safety reasons, the joining tools requires two-hand operation to trigger the punching process. In its manually guided function, the robot also requires an enabling device and several movement modes for quick and precise positioning at the joining point. Holistic operation of the robot/riveting tool system has been implemented to ensure intuitive operation, and hence high acceptance among the workforce.

1 *Physical strain during manual assembly*
2 *Manually guided robot system*
3 *Combined production data processing and information visualisation*

Combined process data acquisition

A further advantage of the developed assistance system is the possibility of using the integrated sensors. On the one hand, the tool is intelligent and can record the force-displacement curves for each riveting process, and hence provide an evaluation of the process. On the other hand, the position data of the robot can be used for automatic correlation of the process data to the riveting positions. Automatic process documentation was made possible by linking tool and robot system.

Intelligent information visualisation

In order to make the data accessible to the worker during the riveting process, an application was developed for information visualisation on a smartphone. The worker has a smartphone permanently attached to his lower arm during assembly on which information of the robot system and the current assembly process is displayed. In addition, he has the possibility of changing preferences for the process or robot system directly via the smartphone. Quality assurance as an important aspect of aircraft construction is greatly simplified by the smartphone by ensuring continuous process documentation. In the application, the self-piercing rivets are assigned to the respective riveting positions in the aircraft fuselage which is intuitively visualised. Manual reworking after the assembly process, if necessary, can then be carried out quickly and in a targeted manner.

Benefits

By providing physical relief for the workers, the intelligent assistance system based on human-robot collaboration leads to an improvement in ergonomics. The combined process data acquisition allows the transparency and quality of the joining process during aircraft final assembly to be increased. Thanks to the provision of digital information on the smartphone, the workers are guided intuitively through the assembly process.

First tests under real conditions in the aircraft fuselage showed the potential of the application and the acceptance by the workers. In future, the fundamental system should be extended to worldwide use in the riveting of the stringers and stringer couplings, and also transferred to further areas of the aircraft final assembly.

Participating partners

Airbus Operations GmbH, Hamburg; TOX® PRESSOTECHNIK GmbH & Co. KG, Weingarten

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ACCREDITED TEST LABORATORY

DAkkS
Deutsche
Akkreditierungsstelle
D-K-18752-01-00

The test laboratory of the Fraunhofer IGP is closely involved in the ongoing research projects by the faculties of the Institute. Test functions from the business sector are also handled here. In order to meet the high quality requirements from research and business, the test laboratory is accredited in accordance to DIN EN ISO/IEC 17025:2005 by the German accreditation body DAkkS.

Since the founding of the test laboratory, extensive know-how has been built up in the fields of experimental studies into materials, fasteners, joints and coating systems. The main focus of the work is not only on accredited tests, but also on standardised and non-standardised tests and component testing. The focus in these areas lies on the high standards of quality and the reproducibility of the tests. In addition, further standardised processes are being continuously added to the portfolio. The testing services offered by the laboratory include mechanical and technological tests, leak testing, corrosion tests, chemical and physical tests and surface characterisations. The laboratories have a broad machine park available for these applications. The testing portfolio is constantly being expanded and currently comprises the following tests:

Mechanical-technical testing

- Tensile tests
- fatigue tests
- 3 and 4-point bending tests
- Mechanically-joined connections: Friction coefficient, transverse longitudinal tensile capacity, tightening, torque and pre-loading force behaviour, vibration resistance
- Adhesives joints, single- and multi-shear connections, caterpillar peeling tests
- Notched bar impact tests
- Vickers hardness testing

Leak testing by means of the helium leak test

- Container and tank tests
- Leak detection
- Testing of joints

Corrosion testing

- Vehicle painting (VDA)
- Coating systems for steel structures (ISO 12944-6, ISO 20340)
- Corrosion tests in artificial atmosphere
- Outdoor weathering of coatings

Chemical-physical testing

- Calcination of FRP composites
- Spark discharge spectrometry of metals
- Determination of the hydrogen content in arc welded material

In addition to the broad range of testing services offered, the institute also has a metallography laboratory. Here we employ two material tester who are responsible for the preparation and conduction of various test procedures and for the analysis and documentation.

1 *Sliding load test*

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The tests in the test laboratory department are conducted by a competent team of engineers and technicians with many years of experience in the development and configuration of measuring and testing apparatus. The main focuses of the work extend from the development and performance of the tests through to their evaluation.

Machines

- Universal testing machines: Tensile / compressive tests up to 1000 kN, -80…250 °C
- Dynamic testing machines up to 1000 kN
- High-frequency pulsators up to 100 kN
- Drop weight tester up to 90 kN
- Torque test bench up to 500 Nm
- Vickers hardness testing machine up to HV30
- Roughness measuring machine down to 300 µm
- Coat thickness measuring machine down to 3000 µm

INSPECTION, MONITORING AND CERTIFICATION BODY ACCORDING TO LBO

PÜZ Body MVO08 according to State Building Code

Products or types for which recognised technical rules do not yet exist require building inspectorate suitability certification before they can be used in building authority approvals applications/areas. For general construction supervision permits (abZ) with approvals numbers Z-14.1-… and Z-14.4-… (connecting elements), the Fraunhofer IGP has been recognised by the German Institute for Civil Engineering (DIBt) as an inspection, monitoring and certification body (MVO08) according to the state building code since 2014. The recognition as a monitoring and
certification body was successfully extended in 2018 with the approvals numbers Z-30.6-… (welded steel parts) and Z-14.9-… (structural anchorings of attachment points for anchor devices). In addition, recognition was gained for the approval group "Parts of structural steel welded using a standardised process with special application" (approval number Z-30.6-…) as Germany's first and currently only testing body.

The Fraunhofer IGP takes on supervision and certification orders (System ÜZ) in Germany and abroad. The functions of the supervisory body thereby comprise the inspection of the manufacturing works on site with respect to the personnel and equipment preconditions for consistently correct manufacturing. The supervisory body is also responsible for auditing the works' in-house production control to ensure the product properties. External supervision thus comprises an inspection of the building products for compliance with the underlying technical specification (abZ).

The certification body then performs the final evaluation of the reports submitted by the supervisory body with regard to the granting, renewal or revocation of the certificates of conformity. If the evaluation is positive, the manufacturer is both entitled and obliged to mark the building products or building types with the symbol of conformity (Ü symbol).

For certain building products or building types, the declaration of conformity can be made by the manufacturer (ÜHP system). In that case, the testing body of the Fraunhofer IGP can carry out an initial test of the building product or building type for conformity with the demands of the underlying abZ.

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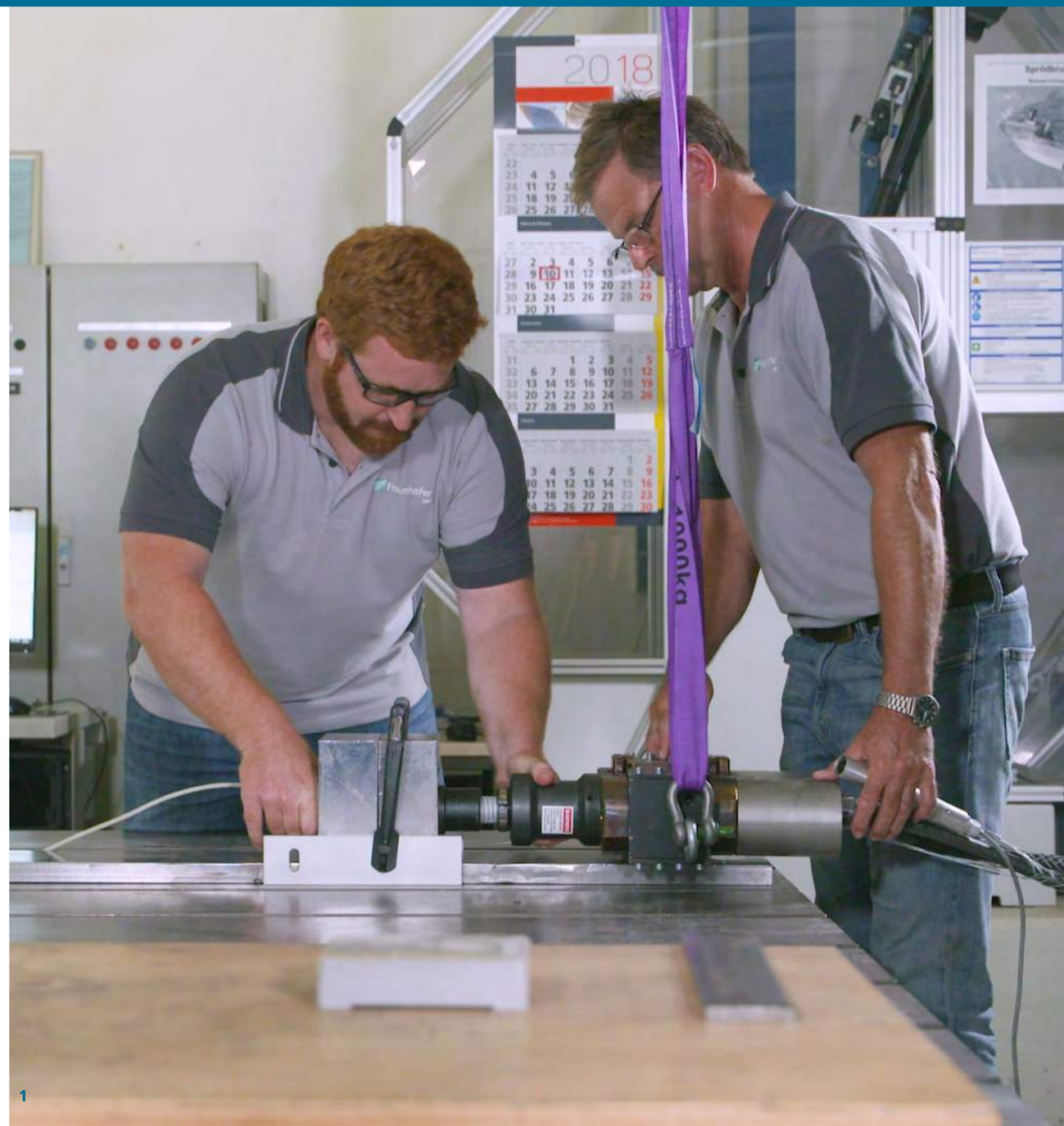

1 *Florian Knöchelmann and Detlef Krüger setting up the testing machine*

EDUCATION, APPRENTICESHIP AND ADVANCED TRAINING

Under our cooperation agreement, the Shipbuilding and Ocean Technology Faculty at the University of Rostock and Fraunhofer IGP have worked together closely in education and research for many years.

The Chair of Manufacturing Engineering provides the training in the production and manufacturing modules as part of the bachelor and masters curricula. We work closely with the topics of the Chair of Joining Technology to give the students a complete picture of all the possible production methods.

Since 1998, the lectures at the university have been closely coordinated with the industrial research. On the continuously growing research activities of shipbuilding and steel engineering, mechanical engineering and vehicle construction in joining technology as well as production technology and on the basis of wide-ranging research projects in the field of automation technology, the production organization and the metrology arise for students interesting basic and application-oriented tasks in the context of study and final theses, which facilitate the transition from study to professional practice.

Many of our graduates were able to take up interesting duties in industry or even in research and are still closely linked to the Chair of Manufacturing Engineering and Joining Technology even today through an alumni network.

In addition to the university education of the students, we also focus on continuing vocational training. In cooperation with the Fraunhofer Research Institution for Large Structures in Production Engineering IGP, the Bonding Technology Further Training Centre of the Fraunhofer IFAM offers a one-week course for bonding technicians and a three-week course for the further training of supervisors, technicians and engineers to bonding experts in Rostock.

1 *Seminar on adhesive bonding technology, presented by Sven Wachtmann*

Contact for university education

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1

Further training for bonding technicians and experts

With the increasing material mix of metals, plastics and composites, bonding is growing in importance as a joining method. The publication of the new DIN 2304 "Adhesive bonding technology - Quality requirements for adhesive bonding processes" makes new demands on the users. In order to enable companies to exploit the potentials of adhesive bonding technology, the the Bonding Technology Further Training Centre of the Fraunhofer IFAM in cooperation with the Fraunhofer Research Institution for Large Structures in Production Engineering IGP in Rostock offers not only one-week courses for bonding technicians, but also a three-week course for the further training of supervisors, technicians and engineers to bonding experts.

Bonding technicians TO GUIDELINES DVS® / EWF 3305 AND EWF 515
The participants are qualified for work in industrial production. The one-week course provides a basic understanding of gluing and bonding so that the peculiarities of the bonding process can be understood and taken into account in production. Work instructions thus become transparent in their relevant contexts and effects. Equipped with this knowledge, bonding technicians can carry out bonding work correctly and by themselves.

Bonding experts TO GUIDELINES DVS® / EWF 3301 AND EWF 516
In the three-week course, the participants are qualified for the use of adhesive bonding technology in industrial production and product development. On successful completion of the course, they are qualified to draw up working instructions and to instruct employees and bonding technicians in the theory and practice of adhesive bonding technology. Adhesive bonding processes can be planned, organised and supervised by them, and process parameters can be reviewed and varied, if necessary. They are able to recognise irregularities in production and to react to these. The successful final test serves of proof of competence and qualifies the holder to take on the duties and competences of the responsible adhesive bonding supervisor (to DIN 6701-2 or Guidelines DVS® 3310 and 3311).

Both courses are recognised in accordance with DIN 2304 and DIN 6701.

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Range of courses of the Chairs of Manufacturing Engineering and Joining Technology

MANUFACTURING	WELDING	ORGANISATION	QUALITY	AUTOMATION
Manufacturing Engineering	Welding technologies	Plant Management (Dr. Schröder)	Quality Management	Automation in production and assembly
Selected production methods	Welding construction	Production management (Dr. Schröder)	Production Measurement Technology	Control Engineering
Production equipment	Welding metallurgy		Technical Documentation	Robotics (Prof. Woernle)
Shipbuilding technology		Lecture series MHI Industry 4.0 for engineers		
Ergonomics				

Universität Rostock Traditio et Innovatio

Chair of Manufacturing Engineering

The Chair of Manufacturing Engineering sees itself as an integral part of the Faculty for Machine Engineering and Ship Technology at the University of Rostock and provides the training in the production and manufacturing modules as part of the bachelor and masters curricula. We work closely with the topics of the Chair of Joining Technology to give the students a complete picture of all the possible production methods.
In the training, the Chair of Manufacturing Engineering currently reaches 195 students in the summer semester and 421 students in the winter semester (as of 2018) with its events. These include the students of machine engineering and business engineering, but also students from the institute of education.
The cooperation with the Fraunhofer IGP opens up the possibility of integrating application-relevant research topics into the training. Employees of the Fraunhofer IGP, for example, work as guest lecturers at the Chair of Manufacturing Engineering. Furthermore, through its contacts to numerous lecturers from industry and other industry-oriented research centres of other universities, the Chair gives the students the opportunity to gain an up-to-date picture of the industrial implementation. Our lecturers come i.a. from Dürr AG, TKMS Blohm+Voss, SLV Rostock, Nordic Yards, Salzgitter AG and the Laboratory for Materials and Joining Technology at the University of Paderborn.

We offer the students a large number of interesting student projects (bachelor, graduate and masters theses). Particularly through the cooperation with the Fraunhofer IGP, we can involve the students in industry-relevant topics and open up links to later fields of work of the graduates.
Since the 2018 semester, we have been actively involved in the Industry 4.0 multimedia joint lecture that is held at 14 locations in Germany, organised as part of the cooperation in the MHI (Scientific Association for Assembly, Handling and Industrial Robotics e.V.).

1 *The lecture on manufacturing engineering, presented by Prof. Flügge*

Chair of Manufacturing Engineering

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Chair of Joining Technology

The Chair of Joining Technology at the University of Rostock dates back to the founding of the Technical Faculty in 1951 with the functional symbiosis of material engineering and welding engineering with shipbuilding orientation. Since 1992, a manufacturing engineering orientation of joining technology has been promoted which, alongside welding engineering, has now been expanded to include mechanical and hybrid joining technologies, brazing and thermal spraying technologies. Today the Chair of Joining Technology in the Faculty for Machine Engineering and Ship Technology can offer in-depth welding and joining technology training for the degree courses machine engineering, business engineering and vocational education in the masters curriculum that are attended by around 30 masterands per semester. A further technical orientation that is widely followed consists of the recognition of the welding engineering modules and special practical training as part of a certified welding engineer qualification.

As part of the cooperation with the Fraunhofer IGP, joining technology training at the university has been closely linked to industrial research since 1998. Through the shipbuilding and structural steel and machine and motor vehicle engineering research activities that have steadily grown since then, the students can work on interesting basic research and application. oriented tasks as part of their study and thesis work that simplifies the transition from studying to their professional life.
Within the Faculty for Machine Engineering and Ship Technology there are a wide range of courses in joining technology that can be combined with other chairs, in particular with the Chairs of Manufacturing Engineering, Material Engineering and Construction Engineering and with the Chairs of Wind Energy Technology, Structural Mechanics and Ocean Technology. These are completed with offerings geared to the requirements as engineer with suitable further events, for example by the German Association for Welding and Related Processes, coordinated by the Chair of Joining Technology.

2 *Prof. Henkel in the seminar on submerged-arc welding*

Chair of Joining Technology

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SME 4.0–COMPETENCE CENTER ROSTOCK

1

Challenge

With more than 50% of the whole added value, small and medium-sized enterprises (SME) form the backbone of the German economy. Although many SMEs are able to work very efficiently with analogue systems even today, a growing digitisation and networking of the world economy is to be observed. That will present these companies with new challenges in future. It is therefore essential that the digital competence of the SMEs in Mecklenburg-Western Pomerania is increased. A particular focus here is on the networking of the regional economy and the innovative digitisation of small and medium-sized enterprises from the target groups of health and social services, tourism and the manufacturing sector. Extensive offers of support are in place to enable the regional companies to safeguard their current market position and to also break into other disruptive fields of business.

Solution

A competence center for the companies in Mecklenburg-Western Pomerania is being set up to support the companies in their digital transformation. The project partners comprising the universities of the state together with the Fraunhofer IGP operate local offices in Rostock that serve as the first point of contact for interested companies. The staff in these offices help the companies from the target sectors in the choice of the right support activity and provide extensive information on the potentials and challenges of digitisation.

Target branches

Within the transfer project, the competence center focuses on the interests of small and medium-sized enterprises from the tourism, health tourism, health management, medical technology and manufacturing sectors. An expansion of the sectors to be supported is planned during the course of the project.

Service portfolio

Thanks to a three-step system, interested companies quickly find help on the subject of digitisation. In addition to raising the awareness for digital transformation through various information events and topic workshops that are held at the offices of the competence centre, there is also the possibility for the companies to analyse their own current level of digitisation by means of a quick-check on a specially created website. In addition, the Fraunhofer IGP operates demonstrators at two different locations with which digitisation is illustrated for specific solutions. At the offices of the competence center, possibilities of digitisation are visualised within assistance systems in medical technology. Here an occupancy planner helps to make optimum use of the cost-intensive areas of clinics and medical practices. As a result, idle times can be avoided and costs saved without neglecting the well-being of the patients.
At the Fraunhofer IGP, traceability can be viewed in one-off production where the use of different identifications and localisation technologies and the evaluation of the data obtained are demonstrated.
In addition to the demonstrators offered, the Fraunhofer IGP conducts customer-specific information meetings with SMEs from the manufacturing industry and provides information in a personal atmosphere about targeted measures for the targeted implementation of digitization technologies.

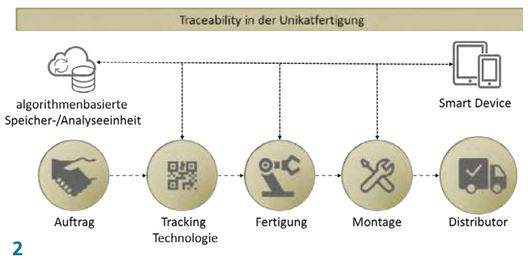
1 *Digital assistance systems in medicine: digital operating theatre planning*
2 *Use of localisation technologies: Traceability in one-off production*

Various training courses are also offered as a further step during the qualification. In two basic training courses, companies are introduced to the fundamentals of assistance systems in assembly and the shop floor digitisation in SMEs. And to also ensure a quick know-how transfer to the SMEs even at a higher level, the Fraunhofer IGP offers two further courses on the topics of data analysis and localisation in production.

In a third stage, the Fraunhofer IGP supports the exemplary implementation of customised digitisation solutions. Here interested SMEs are informed about the individual possibilities and helped in their decision-making.

Benefits

The extensive and widespread cross-medial dissemination of know-how on the subject of digitisation allows a quick raising of awareness among the regional companies. It is hoped that the many information events and training courses will help to quickly raise the degree of digitisation. Together with a widespread expansion of broadband, new disruptive business models could thus be developed and successfully operated by companies in the target sectors.



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NETWORKS, ALLIANCES AND COMMITTEE WORK

Fraunhofer Alliance Production

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Committee work

Center of Maritime Technologies
Prof. Dr.-Ing. W. Flügge – Member of the Technical Advisory Board

German Association for Welding and Related Processes e.V. (DVS)
Prof. Dr.-Ing. habil. K.-M. Henkel – Chairman of the state association M-WP

Maritime Alliance Baltic Sea Region e.V.
Dipl.-Wirt.-Ing. J. Sender – Chairman

Kooperationsverbund RIC MAZA MV e.V.
Dipl.-Wirt.-Ing. J. Sender – Member of the Board of Management

Technology and Innovation Group Business/Science M-WP
Prof. Dr.-Ing. M.-C. Wanner – Member

Scientific Association for Assembly, Handling and Industrial Robotics
Prof. Dr.-Ing. M.-C. Wanner – Member

Working group XXL products
Prof. Dr.-Ing. W. Flügge – Member

German Institute for Civil Engineering (DIBt)
Dr.-Ing. R. Glienke – Member of the expert committee SVA "Metal structures and composite structures"

European Research Association for Sheet Metal Processing e.V.
M.Sc. M. Schwarz – Member – Joint committee DVS / EFB AGMF3/V10.3 "Mechanical joining" – Blind rivets and lockbolts
Dipl.-Wirt.-Ing. C. Blunk – Member – Joint committee DVS / EFB AGMF3/V10.3 "Mechanical joining" – Blind rivets and lockbolts
Dipl.-Ing. C. Denkert – Vice Chairman/Secretary – Joint committee DVS / EFB AGMF4/V10.4 "Mechanical joining" – Functional elements
Dipl.-Ing. C. Denkert – Member – Joint committee DVS / EFB AGMF7/V10.7 "Mechanical joining" – Design and calculation
Dipl.-Ing. M. Dörre – Member – Joint committee DVS / EFB AGMF4/V10.4 "Mechanical joining" – Functional elements
M.Sc. R. Staschko – Member – Joint committee DVS / EFB AG MF1/V10.1 "Mechanical joining" – Punch-riveting
Dr.-Ing. N. Fuchs – Member – Joint committee DVS / EFB AGMF8/V10.8 "Mechanical joining" V10.8 – Testing and joining properties

Society for Corrosion Protection e.V., Working Party Wind Energy (GfKORR)
Dipl.-Wirt.-Ing. M. Irmer - Member

Hanse Aerospace e. V., Hamburg
Prof. Dr.-Ing. W. Flügge – Member of the Technical Advisory Board

REFA State Association Mecklenburg-Western Pomerania e.V.
Dipl.-Wirt.-Ing. J. Sender – Member of the Board of Management

Shipbuilding Association
Prof. Dr.-Ing. M.-C. Wanner – Head of the Expert Committee Work Organization and Production Engineering, Member of the Technical Scientific Advisory Council

Expert activities

Working group of the industrial research association "Otto von Guericke" e.V.
Prof. Dr.-Ing. W. Flügge, Prof. Dr.-Ing. habil. K.-M. Henkel, Prof. Dr.-Ing. M.-C. Wanner – Expert Assessors

Federal Ministry of Research and Technology
Prof. Dr.-Ing. M.-C. Wanner – expert assessor for the development scheme "Innovative shipbuilding secures competitive jobs"

German Research Association
Prof. Dr.-Ing. W. Flügge - expert assessor
Prof. Dr.-Ing. M.-C. Wanner – expert assessor

Standardisation work

Deutsches Institut für Normung e.V.
Prof. Dr.-Ing. R. Glienke – member of the Advisory Board NA 092
DIN standards committee welding and related processes (NAS)

DIN standards committee welding and related processes
Dr.-Ing. N. Fuchs – member – NA 092-00-23 AA: Working committee Mechanical joining (DVS V 10.8)
Dr.-Ing. N. Glück – member – NA 092-00-28-01: Process chain bonding technology
Dr.-Ing. N. Glück – member – NA 092-00-28-02: Bonding of composite fibre-reinforced plastics

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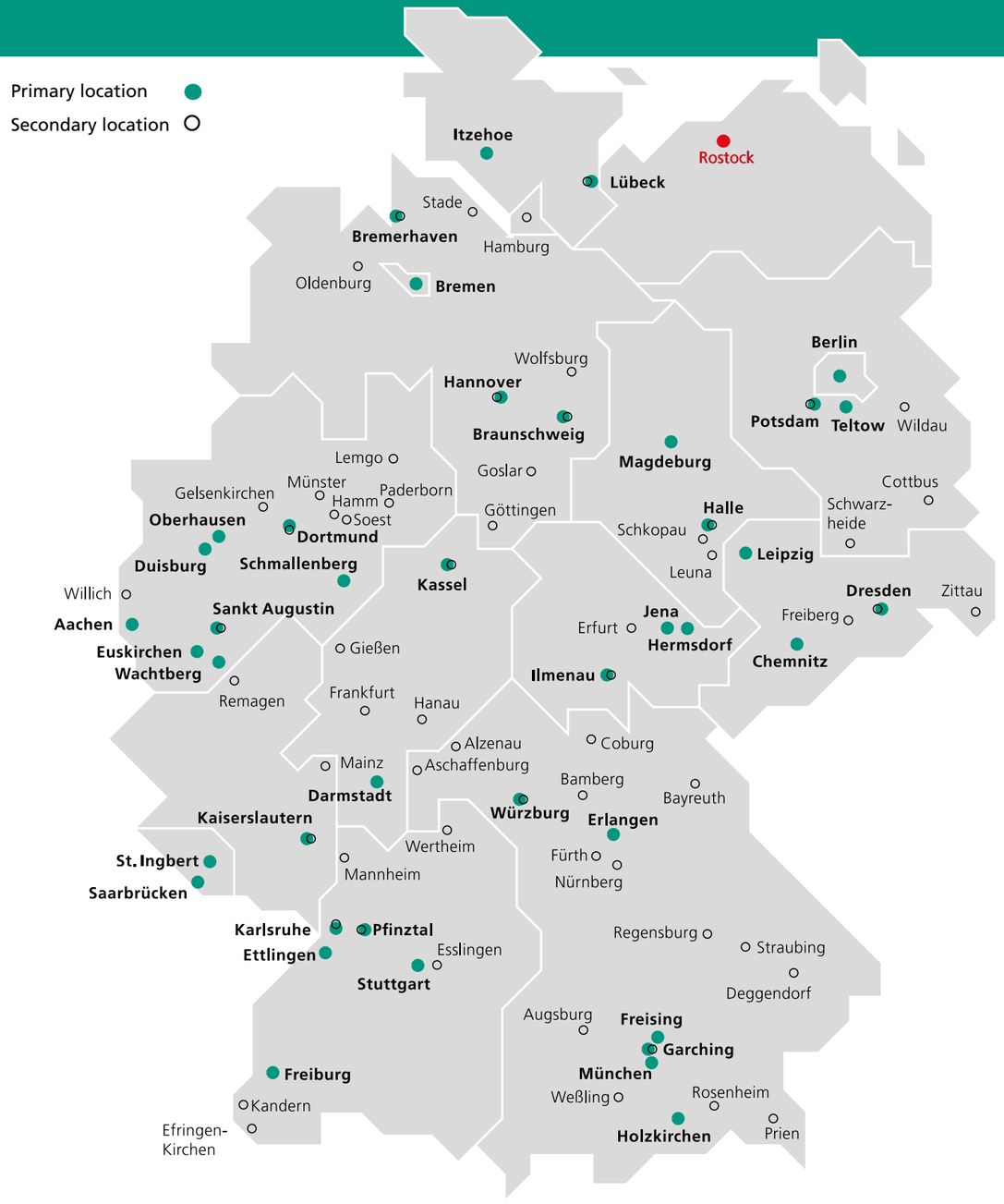

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Annual Report 2017/2018
Activities and Results of the Fraunhofer IGP

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Editors
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Layout and production
M.A. Verena Schulz

Print
Druckerei WEIDNER GmbH

Period under review
1 July 2017 to 31 July 2018

Annual Report 2017/2018

Title photo: *Welcome to the Fraunhofer IGP*