Quality Control of High Tension 3D-NVEB-Weld Joints

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Abstract. Within the scope of the CRC 675 "Production of high strength metallic structures and joints by specifically setting local properties", particularly in the sub project C4 "Calibrating graded material properties and assessing the quality of high strength 3D NVEB-welded joints", the properties of components are individually adapted to correspond to the loading profile. For this assigned task, it is necessary to adapt and improve the beam position, the process control as well as the defect inspection of the weld seam with respect to high quality welded joints.

Introduction

The relatively new and very powerful non-vacuum electron beam welding (NVEB-welding) provides excellent welding properties with respect to gap-bridging ability and the heat affect zone and is characterised by its favourable qualities for welding both thick as well as thin walled plate and sheet material. A distinct advantage of this process over vacuum electron beam welding is working at atmospheric pressure whereby a time-consuming evacuation of the weld-region is eliminated. The energy input together with the formation of the weld-pool are particularly important with regard to the formation of the microstructure, zero-defect tolerance and the material condition adjacent to the weld-seam and its heat affected zone.

Within this research project, methods and processes for controlling quality during NVEB welding are investigated and developed with respect to the high standards of modern welding processes concerning economic efficiency and the quality of high strength welded joints. Currently, actual quality assurance procedures neither provide sufficient definition nor even retrospectively intervene in the process. For this reason, the aim of this work is to recognise and specifically eliminate possible faults prior to or during the welding process by means of intervening in the process control.

For this purpose, a method is presented which traces the weld seam contour in advance of the processing which utilises eddy-current sensors, detectors for recording the process-intrinsic scatter-beam reflections and X-ray bremsstrahlung as well as analyses the energy conversion and the weld-pool dynamics. By combining these two methods, an effective quality assurance is established for NVEB welding.

1. State of the technology prior to project's commencement

1.1 Manufacturing high quality welded joints

NEVB welding is an established welding method for manufacturing high quality welded joints. In contrast to other methods, thick and thin plate material as well as dissimilar parent materials can be welded together without difficulty. Another advantage compared to other welding technologies; for instance laser technology, is the good overall efficiency of approx. 40 - 50 % [1]. The high joining rates and the high process tolerances attainable by using a widened electron beam are further favourable characteristics which clearly underline the qualification of the NVEB welding method.

1.2 Tracing the welding-gap's contour

The most frequently used method to recognise the weld-gap during electron-beam welding is based on the beam's deflection and the measurement of the occurring electron and X-ray scattered radiation. The first investigations of this were described by Eichhorn [2]. Bolmsjö [3] described an online inspection technology which also made use of the electron-beam's deflection and the evaluation of the reflected electron-scattering However, these results are only applicable to vacuum electron beam welding.

The application of optical and laser optical systems, which are also described in [3], to recognise joints also provide insufficient results. Owing to the continuously changing surface and thus its fluctuating reflective characteristics as well as the various geometric ratios at the section's edge, these investigations only resulted in insufficient positioning precision.

In addition to this, optical systems have the disadvantage that they tend to soil, due to the frequently harsh welding environment, and consequently can not provide consistent results.

Different materials to be welded, residual stress conditions, edge misalignment and chamfering exclude the application of ultrasonic techniques since here, as mentioned in [4], it was not possible to obtain acceptably precise measurements.

In the sources [5] and [6], detectors were investigated for recording β reflected electron-scattering. A prerequisite for this method is very precise control of the process. Owing to the use of an electron-beam as the energy source, this system has a significant time-lag and thus can not be considered for online quality assurance.

A very detailed overview of the electron-beam welding's implementation and assessment is presented in [7]. Unfortunately, the evaluation is related exclusively to welded joints in aluminium where errors in the seam's profile were not considered.

1.3 Process monitoring

The discussions of [8] refer exclusively to the temperature measurements during conductive laser-welding, whereas [9] describes the application of digital image processing for TIG welding. It was not possible to demonstrate the use of these two procedures to NVEB welding.

Exploiting the process-intrinsic effects for radiographically analysing weld-pools as a possibility for characterising welding processes is described in [10] and [11]. These discussions are related to vacuum electron-beam welding and can not be easily transferred to NVEB welding owing to the widened electron beam. Recording radiation emissions from the weld pool in lightweight metal components is considered in [12]. The objective is to characterise the welding process by means of the infrared radiation which is emitted from the keyhole. Here, the weld seams are produced under vacuum by means of electron-beam or laser-beam welding. By correlating the infrared sensor's measured results as well as the penetration current, it was then possible to retrospectively discern the weld seam's irregularities in the process. These investigations form a good basis for further research in this field.

2. Results from the project

3.1 Positioning of the beam's head to the weld gap

In order to produce a weld seam which is as defect-free as possible and to avoid one-sided fusion defects, it is necessary for the electron beam to precisely follow the weld gap. For this reason, an online weld-gap tracing system based on eddy-current inspection technology was developed which is described in detail in the following.

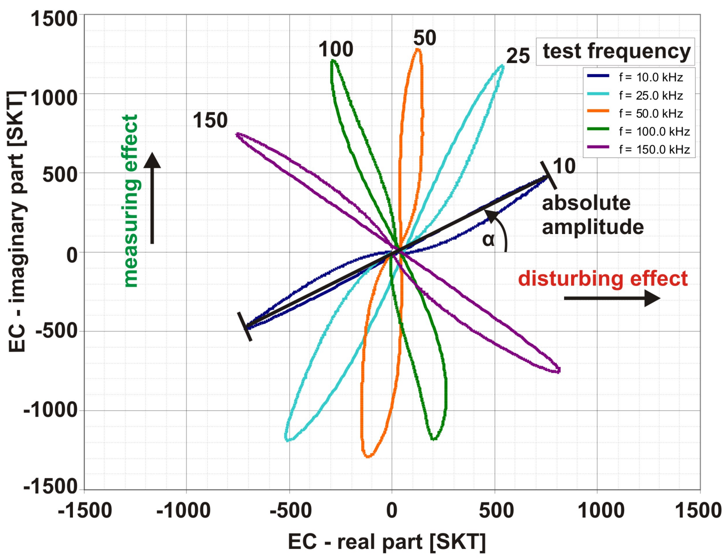

Fig. 1. Separation of the useful and the spurious signal components EC-phase separation

In developing the eddy-current (EC) sensors, several fundamental characteristics must be observed: high sensitivity of the measurements regarding the weld gap, good signal to noise ratio and robustness in relation to different spurious influences. Owing to these problematical requirements, an EC-differential sensor with a T-configuration was tested. The gap's position induces a distortion of the magnetic field orthogonal to the gap's direction on which the measuring effect of this type of sensor is mainly based. By varying the test frequency, the useful signal can be separated from the interference signal via the phase selection procedure [13].

In order to obtain a rotation of the phase between useful (y-components) and interference (x-components) signals, an optimum test frequency of 50 kHz results for the sensor used here.

Since this is a non-contact method, different separation distances were employed and their effects on the eddy current signal were documented. Decreasing amplitudes can be observed with increasing working-distances between the sensor and the component's surface. However, for a working-distance of up to 2.5 mm, this has no decisive effect on the positional accuracy which, within this range, is ± 50 µm.

Edge misalignment and chamfering have a significant influence on the eddy-current's signals. By means of compensating for the spurious variables, this change is shown only in the x-components; that is, in the interference signals and thereby, similar to the distance effect, has only a slight influence on the useful signal [14].

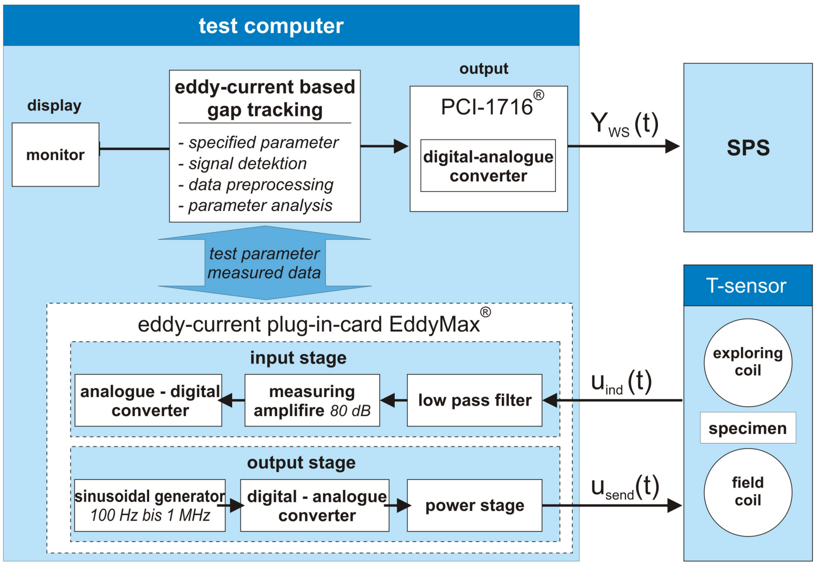

Fig. 2. EC-T-sensor testing system for gap tracking and gap positioning

A data processing computer including an eddy-current card and the testing software ECGT (eddy-current based gap tracing) is required for implementing the EC sensor online. This enables the electron-beam to be automatically tracked along the weld joint. The eddy-current sensor is positioned during the weld pool's forward movement with the aid of a linear axis.

After extensive parameter testing, the following settings have been proven as expedient for the testing task. Test frequency 20 - 200 kHz with a digital control signal cycle rate of 2 kHz [13].

3.2 Weld-pool monitoring using radiation detectors

Monitoring the weld pool during NVEB welding is based on measuring the process-intrinsic radiation. On processing materials using an electron-beam, an interaction occurs in the material in which reflected electron-scattering and x-ray bremsstrahlung arise. These effects can be recorded using appropriate detectors and are evaluated by means of the associated software. In order to realise this, NaI-detectors (sodium iodide, doped with thallium) and YAP-detectors (yttrium aluminium perovskite, doped with cerium) are employed to record the x-ray bremsstrahlung and reflected electron-scattering, respectively. To position the detectors, a support was designed which can be directly adapted to the NVEB equipment and accommodates up to 9 detectors. In this way, the detectors are directly focused at the weld pool. Owing to the extremely intense radiation which is generated during the welding process, it is necessary to shield the detectors against scattered radiation by using a leaded bronze sheath. In order to enable specific weld pool regions to be monitored and to adjust the counting rate to the maximum measurable counts per second, an additional collimating system was integrated into the sheath. The detector's adaptation to the equipment as well as its sheathing is schematically depicted in Fig. 3.

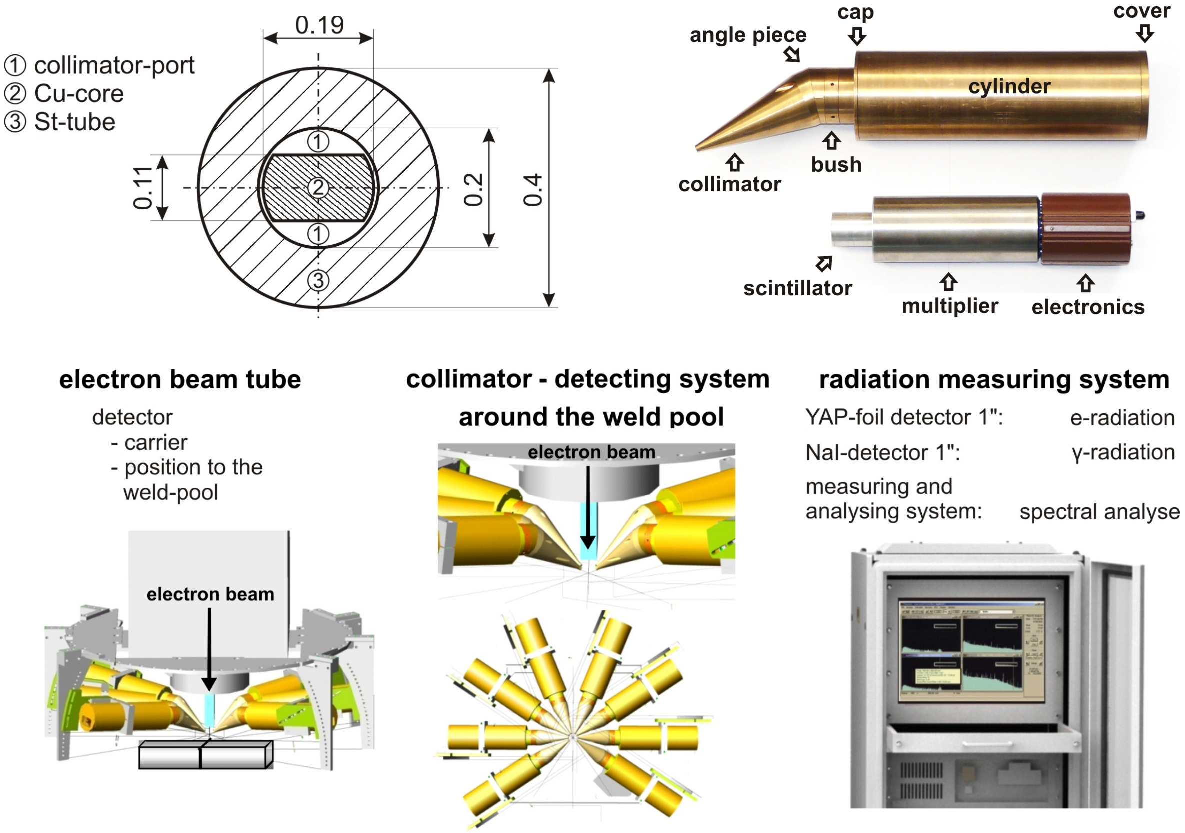

Fig. 3. NaI- and YAP-detector and weld-pool monitoring and analysis

The detectors were calibrated with the aid of radioactive sources. An Am241-source was employed to determine the discrete energy lines in the decisive energy ranges. As an example, two energy spectra are depicted in Fig. 4 for the NaI and the YAP detectors [15].

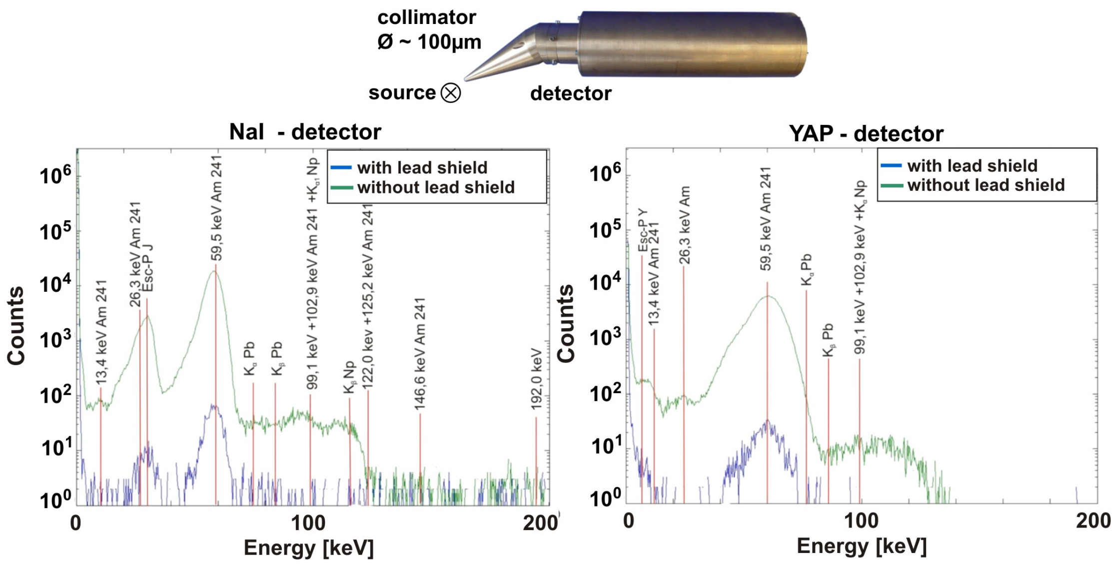

Fig. 4. Energy spectra to calibrate the detectors

The Institute of Materials Science's NVEB equipment at the Leibniz University Hanover (LUH) was used for the welding tests. This operates using an electron current of 1 to 140 mA, a maximum beam power of 25 kW and a maximum accelerating voltage of 175 kV. During the initial tests, the measuring system's dead times were too high for detecting measured values owing to the too high x-ray beam emission in the weld pool and radiation scatter. For this reason, it was necessary to furnish the detector with an additional 9 mm thick lead sheath.

The welding tests were carried out on plate material having artificially introduced defects. The artificial manipulations include drilled holes of differing diameters as well as varying depths into the plate's surface, locally and conically widened joint gaps. These defects lead to local reductions in the interaction between the electron-beam and the material. As a consequence, the count rate falls in these regions. These drops in count rate are measurable and are evaluated with the aid of the software [15].

As an example, several graphs are depicted of the described drop in impulse owing to defects in the component.

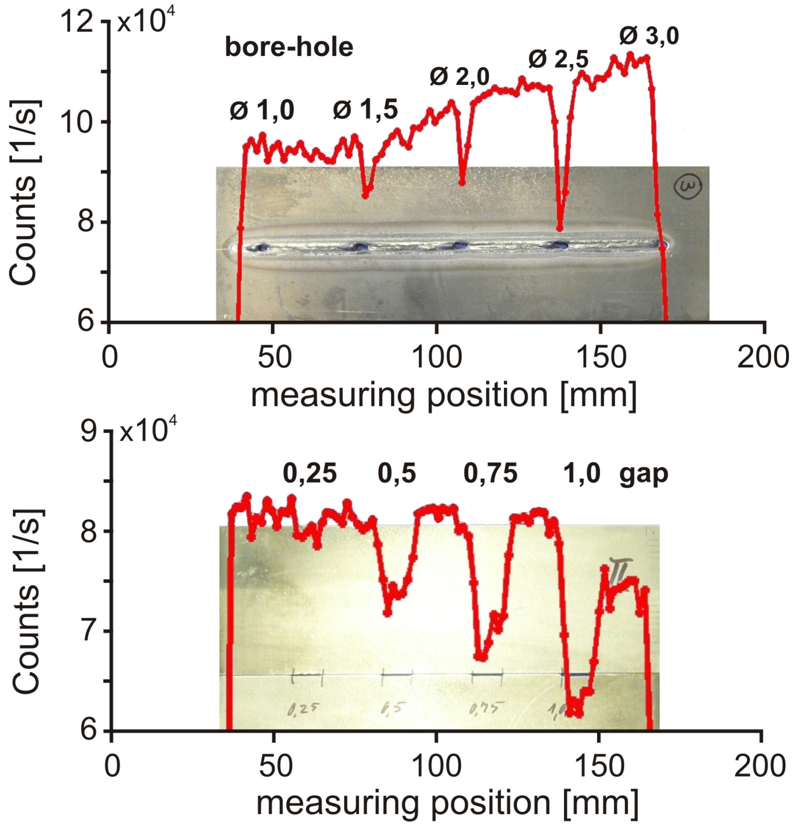

Fig. 5. Radiation detection of irregularities in the weld gap – boreholes in the gap and local gap widening

During welding of thick walled plate material, the keyhole effect plays an important role. Here the stability of the keyhole along the entire length of the weld's seam is decisive for the weld seam's zero-defect tolerance. Initial tests to monitor the keyhole's stability were performed on 4 mm thick plate possessing blind-holes of differing depths which were introduced into the plate's proximal and distal sides. For these tests, one detector was focused on the component's upper surface (proximal), a second on its underside (distal). As a consequence of the different holes, various radiation shielding effects occurred due to the component. The deeper the introduced defect, the greater the measurable impulse rate increased on the component's distal side. Corresponding to this, a drop in the impulse rate occurred which was measured on the component's proximal side. A correlation of the measured values from both detectors admits the possibility of determining the depth and thus making an assertion about the keyhole effect [13]. Specific changes in the count rate must be investigated in further tests.

3. Summary and prospects

In order to fulfil the high quality standards of welded joints even for new joining methods, new technologies must be developed and adapted to the already existing systems. Adequate avoidance of defects and zero-defect tolerance can only be obtained by combining various testing techniques.

By means of applying an eddy-current T-sensor in advance of the process, precise positioning of the electron-beam can be attained for welding seam joints. With the aid of suitable evaluation and control software, the welding beam can trace the seam's profile and thereby fusion defects can be avoided caused by weld-seam misalignment.

By means of employing suitable detectors to register the process-intrinsic X-ray bremsstrahlung and the secondary electrons, the irregularities in the welding process can be detected. Evaluating the impulse rate indicates possible variations in the process during the welding and provides information directly from the weld pool. By processing the signal chronologically with respect to the impulse rate, critical regions of the component can be directly determined from correlations with the feed rate. With regard to continuing research in this field, a new NaI detector will be tested. In doing this, a thinner crystal will be employed by means of which it should be possible to measure the x-ray bremsstrahlung at higher powers. The preliminary fundamental investigations provide very promising results.

All things considered, NVEB welding harbours great potential compared to other welding methods owing to its high overall efficiency, the narrow heat affected zone as well as the high attainable feed rates. According to this, suitable quality assurance provisions must be developed in order to measure process deviations and to implement suitable measures to control the process.

4. Acknowledgements

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5. Literatur

[1] K. Lau, Fr.-W. Bach: Dünn- und Dickblechschweißen mit dem Elektronenstrahl an Atmosphäre. Innovationsforum „Elektronenstrahltechnologie im Maschinen- und Anlagenbau“, Burg bei Magdeburg, 07.-08. März 2007

[2] F. Eichhorn, B. Spies, P. Ritz: Fugenspalterkennung und selbsttätige Nahtfugennachführung beim Elektronenstrahlschweißen. Konferenz-Einzelbericht, XII. Schweißtechnisches Hochschulkolloquium, Haus der Technik, Essen, 22. März 1979, Seiten 117-131

[3] G. Bolmsjö, M. Fridenfalk: Design and validification of a universal 6D-seam tracking system in robotic welding based on laser welding. The Industrial Robot, Band 30 (2003) Heft 5, S. 437-448, ISSN 0143-991X

[4] M. P. Howarth, M. F. Guyote: Wirbelstrom- und Ultraschallsensoren für Lichtbogenschweißroboter. Sensor Review Band 3 (1983) Heft 2, S. 90-93

[5] C. Ribton: Electron beam real-time seam tracking at 30 kW. Zeitschriftenaufsatz, The Industrial Robot, Band 21 (1994) Heft 3, Seite 11-12, ISSN 0143-991X

[6] U. Dilthey, J. Weiser: Adaptive Strahlnachführung beim Elektronenstrahlschweißen. Zeitschriftenaufsatz, Schweißen und Schneiden, Band 46 (1994) Heft 7, Seite 339-340, ISSN 0036-7184

[7] G. Ripper, K. Schmelzeisen: Elektronenstrahlschweißen von Al-Bauteilen an Atmosphäre. Konferenz-Einzelbericht, ASTK, 9. Aachener Schweißtechnik Kolloquium, 29.-30. Juni 2004, Seite 109-119, ISBN 3-8322-2840-3

[8] F. Bardin, R. McBride, A. Moore, S. Morgan, S. Williams, J. Jones, D. P. Hand: Real-time temperature measurement for process monitoring of laser conduction welding. Konferenz-Einzelbericht, ICALEO 2004, 23th International Congress on Application of Lasers & Electro-Optics, Laser materials processing conference and laser microfabrication conference, 4.-7. Oktober 2004, Proceedings Vol.97 (2005), ISBN 0-912035-77-3

[9] T. Müller, K. H. Gaida, K. J. Kern, G. Köhler: Erfahrungen bei der Überwachung und Steuerung von automatischen WIG-Schweißprozessen mittels digitaler Bildverarbeitung. Konferenz-Einzelbericht, Schweißen und Schneiden 99, Weimar, 12.-17. September 1999, DVS-Berichte, Band 204 (1999) Seite 239-242, Verlag für Schweißen und verwandte Verfahren, Düsseldorf, 1999, ISBN 3-87155-661-0, ISSN 0418-9639

[10] S. Böhm: Modellierung und Simulation des Elektronenstrahl-Schweißprozesses unter Berücksichtigung der Elektronenreflexion und der Elektronenstreuung. Dissertation, RWTH Aachen, 1999

[11] V. Braverman, S. Bayakin, V. Bashenko: Control over Electron Beam Welding Process by X-ray radiation from the zone of welding. Tagungsband, 6. Internationale Konf. Strahltechnik, Halle, S.68-74, 2004

[12] J. Overrath, I. Decker, H. Wohlfahrt: Qualitätsüberwachung beim Elektronenstrahlschweißen von Aluminium-Druckguß. Konferenz-Einzelbericht, Internationale Konferenz Schweißtechnik, Werkstoffe und Werkstoffprüfung, Bruchmechanik und Qualitätsmanagement, Wien, 22.-24. September 1997, Proceedings, Band 2 (1997) Seite 679-687, ISBN 3-901167-04-2

[13] M. Diebel, G. Mroz, W. Frackowiak, J. Hauer, W. Reimche, Fr.-W. Bach: Setting of Gradient Material Properties and Quality Control of High Tension 3D NVEB-Weld Joints. Advanced Material Research Vol. 37 (2010), Creation of High Strength Structures and Joints by Setting up Local Material Properties II, Switzerland, ISBN-13, 978-087849-234-3, pp. 375-411

[14] Erstantrag SFB 675: Erzeugung hochfester metallischer Strukturen und Verbindungen durch gezieltes Einstellen lokaler Eigenschaften. Technische Universität Clausthal, Leibniz Universität Hannover, 2006

[15] Fortsetzungsantrag SFB 675: Erzeugung hochfester metallischer Strukturen und Verbindungen durch gezieltes Einstellen lokaler Eigenschaften. Technische Universität Clausthal, Leibniz Universität Hannover, 2010