WELDING AND CUTTING

Technical journal for welding and allied processes

Guide for Authors

Stand: 05/2026

Key points at a glance:

- Submit the manuscript as an MS Word compatible (in these guidelines for readybility only referred to as Word) file. The standard Word styles - Normal, Title, Heading, Caption - should be adapted using this document so that you can start writing your article immediately. Please do not use manual hyphenation to break up a word at the end of a line. Use English UK language setting and spell check. Your Word document will be used for peer review and copy editing. The final layout and typesetting of the article will be done by us.
- Separately label figures (photos, drawings, schematic illustrations, diagrams) and tables (numerical tables, tabular comparisons). Image files must have a minimum resolution of 300 dpi. Accepted file formats: TIFF, JPEG, PNG. Please submit individual figures in separate files; tables should also be submitted in individual Word or Excel files.
- Measurement units must strictly conform to SI standards. Obsolete units such as at.% or wt.% should not be used.
- The journal's design standard does not allow the placement of trademark or registered symbols or the use of all-capital lettering for company and product names.
- When citing sources, please use numerical style: assign numbers to references in the order in which they appear in the text. Please avoid using Word's automatic reference generation.

1 Content and formal text design

1.1 Files

Please submit the following files:

- A complete text file in Word with formulas in-place within the text, but all images and tables embedded at the end of the document for editorial processing and the peer-review procedure.
- Article images also submitted as separate files (TIFF, JPEG, PNG) with min. 300 dpi resolution, named "Fig. 1, Fig. 2"
- Formulas included in the text also contained within individual PDF files named "Formula 1, Formula 2, …".
- Each table in an individual Word or Excel file, using file names "Table 1, Table 2, …".
- (See also the notes in Section 2, Figures and Tables)

1.2 Structure of the article

Your article should contain a maximum of approx. 27,000 characters including spaces and consist of a preface, main text and references.

1.2.1 Preface

The preface contains the following elements in the order listed:

- Full names of all authors without titles
- Article title: max. 100 characters including spaces
- Abstract: max. 1,500 characters including spaces; no paragraphs

1.2.2 Main text

The main text should be structured to a maximum of three levels. The introduction does not require a heading.

- Section headings may contain a maximum of 40 characters.
- The main text should end with a conclusion addressing any further planned investigations and an outlook on unresolved issues or similar topics. For research papers: identify any implications for potential practice.

1.2.3 References

Refer to the corresponding reference using numbers in brackets, for example:

[1] Matting, A., and G. Jacoby: The Degradation of Metallic Materials under Cyclic Loading in Fractography. Aluminium 38 (1962), No. 10, pp. 654–61.

[2] Neumann, A.: Welding Technology Handbook for Designers, Vol. 1, pp. 31–40. DVS Media, Düsseldorf, 1990.

All sources (including online sources) must be cited according to DIN ISO 690:2021-06. Number the references consecutively in the order in which they appear in the text. Please avoid using Word's automatic reference generation if possible.

1.3 Formal text design

The maximum length of the formatted article is 27,000 characters (including spaces).

- WELDING AND CUTTING uses the spellings and language rules recommended by Oxford Dictionary.
- Tabs should only be used for lists and bullet points. Tables should be created in Word using the table editor. Equations and formulas must be numbered consistently using Arabic numerals (in parentheses).

2 Figures and Tables

Figures are important supplementary elements in scientific texts. Please observe the following guidelines:

- A maximum total of 7 figures and tables.
- Drawings, diagrams and images are labelled with “Fig. and a number”
- Figures and tables are numbered consecutively within the article (e.g., Fig. 1, Fig. 2, etc.) and each must be cited at least once in the manuscript text.
- The caption must be placed outside graphic image boundaries. It should describe the content of the figure so that it is self-explanatory.
- Captions must include copyright information (e.g., Fig. 1: text (© Source)). All captions should be grouped together at the end of the article.
- The font used in all figures should be consistent.
- Please avoid effects such as fill patterns, outline fonts, gradients and shadows.
- Figures should preferably be in colour; minimum resolution 300 dpi; and TIFF, JPEG or PNG file formats.

3 Authors

- Word file for each author with titles, first names and last names; current professional/job titles with institution, employer and (optional) e-mail addresses as well as short CV for our on-line-database
- JPG with protrait photo

4 Acknowledgements

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Title
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Chapter heading

Main body

Julius Raute, Jonathan Schmidt, Torsten Jokisch, Max Biegler, Michael Rethmeier

Electron Beam Welding of Additively Manufactured Inconel 939 – Process Characteristics and Achievable Weld Quality

Additive manufacturing technologies such as the laser powder bed fusion provide significant potential for the fabrication of new and replacement parts for stationary gas turbines made of nickel superalloys such as Inconel 939. To enable integration of repaired components into existing assembly units and to overcome dimensional limitations, the additive manufacturing process chain must be expanded to include suitable joining techniques. This work therefore deals with the welding of Inconel 939. It compares cast sheets and sheets produced additively using laser powder bed fusion in terms of their behavior during electron beam welding. The investigation focuses on the achievable seam quality with regard to geometric irregularities and internal defects in the form of microcracks in the heat-affected zone. No differences in the formation of the seam shape between the additively manufactured material and the cast material were found when evaluating the welded samples. The highest quality level for beam-welded seams according to DIN EN ISO 13919-1 was achieved for both materials at a high welding speed of 20 mm/s. Regardless of the manufacturing method, both materials show an increase in crack susceptibility with increasing welding speed. Due to its microstructure the material from additive manufacturing has significantly fewer microcracks overall, which opens up potential for practical application.

1 Introduction

The advantages of laser-based powder bed fusion (PBF-LB/M) are particularly evident when geometrically complex components need to be manufactured. In addition, it offers the possibility of producing undercuts, internal structures such as cooling channels and load adapted designs, which make PBF-LB/M suitable for applications involving components made of materials that are particularly difficult to machine or cost-intensive. A good example is the manufacture of stationary gas turbines, where highly developed nickel-based materials, such as the Inconel 939 (IN939) alloy, are used for the production of blades and vanes. Due to its excellent mechanical, chemical and thermal properties, this alloy with its characteristic high chromium content has established itself as the standard material for numerous applications in gas turbines [1]. Due to their dimensions and complex geometry, turbine components made of IN939 can only be reworked, manufactured or repaired with increased effort and high costs. Previous studies have demonstrated that IN939 can be processed using additive manufacturing methods such as PBF-LB/M and that the process is potentially suitable for both the manufacture of new parts and the repair of worn components [2].

Despite significant progress in recent years, the limited build space of the machines, which restricts the possible component size, remains a challenge for the use of PBF-LB/M systems in gas turbine manufacturing [1]. To overcome this challenge, a reliable joining process for additively manufactured components made of IN939 is required. Precise beam-based welding processes, such as electron beam welding (EBW), appear to be particularly suitable for this purpose. They could enable additively manufactured components to be joined with other PBF-LB/M parts or conventionally manufactured components, thus overcoming the size limitations of powder-bed-based AM. This would also allow the integration of additively manufactured replacement parts into existing assemblies.

Unlike other nickel-based alloys, IN939 is only considered to be partially suitable for welding due to its higher Al and Ti content [1]. Additional uncertainties exist when welding additively manufactured IN939, as the material is already prone to hot cracking as a conventionally cast material [3]. A characteristic feature of IN939 in this context is the occurrence of cracks in the heat-affected zone (HAZ), which are promoted by melting reactions of secondary carbides and parts of the γ'-phase [4].

The cracking tendency of the alloy is already known from the application of tungsten inert gas welding (TIG) and can be addressed by selecting filler wires with lower strength [3] or by prior heat treatment [5]. Nevertheless, these measures also result in lower mechanical strength of the joint. Other approaches to post-treatment show that the resulting cracks can be closed by subsequent hot

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Table heading

Table

Figure
min. 300 dpi

Caption

Subheadline

Table 1: Chemical composition of the powder material in volumetric percent (nickel balanced)

Al	B	C	Co	Cr	N	Nb	O	Ta	Ti	W	Zr
1.89	0.004	0.14	18.99	22.5	0.002	0.97	0.0006	1.41	3.66	2.06	0.03

isostatic pressing, as demonstrated by the work of Xie et al. [6]. However, even with this post-treatment, the sealed cracks can still be identified in the microstructure and it remains unclear whether local weakening of the matrix has a negative impact on the overall mechanical properties. In addition, there is a risk that deviations in the material properties caused by the additive manufacturing process may have additional negative effects on the quality of the joint or even promote the formation of defects.

The use of a beam welding process such as EBW, with a small HAZ and precise control of the seam geometry, appears to be suitable for IN939, as Ni alloys with high fractions of precipitation phases are more prone to cracking in the HAZ [7]. Welding in a high vacuum also appears to be advantageous for process optimization, as the influencing factors of shielding gas coverage and oxidation do not affect the joining process. Initial investigations have already shown that EBW has great potential for joining additively manufactured components made of IN939. For example, an investigation involving test welds on 3 mm thick sheets from the PBF-LB/M process showed that the tendency to cracking in the HAZ is partly parameter-dependent and can be limited to the microscale [8]. However, there is still a lack of process understanding for practical applications, necessitating a more detailed investigation into the occurrence of microcracks, possible seam quality for greater sheet thicknesses, and the interactions between the welding process and the additive manufacturing.

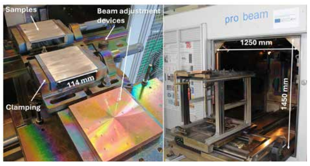

Fig. 1: Test setup: Left: Clamping of the sample sheets; Right: View into the vacuum chamber of the K30 (© Fraunhofer IPK)

2 Materials and methods

2.1 Manufacturing of the PBF-LB/M samples

The additive manufacturing process was carried out on a SLM 280HL system. A total of 12 test sheets measuring 117 mm × 30 mm × 7 mm were produced for welding tests under a protective gas atmosphere of argon 5.0 with an oxygen content of less than 0.2 %. A substrate plate measuring 280 mm × 280 mm made of X15CrNiSi25-21 was used for sample production without additional preheating. The samples were distributed evenly on the substrate plate. In order to restrict the contact line with the coater, all samples were rotated by 12.5° around their z-axis. According to the delivery note of the manufacturer, the powder material used for production had the chemical composition shown in **Table 1**. The particle size distribution according to ASTM B822 showed values for d_{10}, d_{50} and d_{90} of 23 µm, 36 µm and 50 µm. The samples were produced using constant manufacturing parameters with a laser power of 250 W, a scanning speed of 1180 mm/s, and a hatch spacing of 0.08 mm. Taking into account the intended layer thickness of 0.04 mm, this results in a volume energy density of 66 J/mm³. The parameters were selected to match the optimum values for IN939 determined in previous studies [9]. After sample production, standardized post-processing steps were carried out in the form of wire EDM to detach the samples from the substrate plate as well as solution annealing.

2.2 Electron beam welding

An EBG-15-150 K30 system from the manufacturer pro-beam was used for conducting the welding tests. The samples were clamped onto a work platform in the vacuum chamber using a machine vice. All samples were cleaned with acetone prior to welding. **Fig. 1** shows the test setup.

During the welding tests, the vacuum in the chamber ranged from $0{,}5 \cdot 10^{-4}$ mbar to $2 \cdot 10^{-3}$ mbar. To benchmark the welding behavior of the additively manufactured material, 12 bead on plate welds were performed on sheets manufactured using PBF-LB/M and conventional IN939 cast material. The welding parameters were selected based on preliminary tests so that complete penetration could be achieved in all cases. The cast sample sheets were cut to a size of 114 mm × 28 mm × 7 mm using wire EDM. The bead on plate welds were performed in sharp surface focus in the form of a 100 mm long seam at a constant acceleration voltage of 120 kV. **Table 2** provides an overview of the experimental design. Three different welding speeds and four levels of energy per unit length were tested. The beam current was increased stepwise in order to achieve identical energies

References

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Summary
at the end of the article

Acknowledgement
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