Proceedings in Engineering Mechanics
Research, Technology and Education

Lucas F. M. da Silva
Paulo Martins
Uwe Reisgen *Editors*

3rd International Conference on Advanced Joining Processes 2023

Selected Contributions of AJP 2023

Springer

Proceedings in Engineering Mechanics

Research, Technology and Education

This book series publishes the results of meetings dealing with material properties in engineering and science. It covers a wide range of topics, from the fundamentals of materials mechanics and applications for various industries to aspects of scientific training and career development. The volumes in the series are based typically on primary research materials presented at conferences, workshops, and similar scientific meetings, and represent comprehensive scientific and technical studies.

Lucas F. M. da Silva · Paulo Martins · Uwe Reisgen
Editors

3rd International Conference on Advanced Joining Processes 2023

Selected Contributions of AJP 2023

Springer

Editors
Lucas F. M. da Silva
Faculty of Engineering
University of Porto
Porto, Portugal

Paulo Martins
University of Lisbon
IDMEC, Instituto Superior Técnico
Lisbon, Portugal

Uwe Reisgen
Welding and Joining Institute
RWTH Aachen University
Aachen, Nordrhein-Westfalen, Germany

ISSN 2731-0221 ISSN 2731-023X (electronic)
Proceedings in Engineering Mechanics
ISBN 978-3-031-54731-7 ISBN 978-3-031-54732-4 (eBook)
https://doi.org/10.1007/978-3-031-54732-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Editorial

This volume of *Proceedings in Engineering Mechanics—Research, Technology and Education* contains selected papers presented at the 3rd International Conference on Advanced Joining Processes 2023 (AJP 2023), held in Braga (Portugal), October 19–20, 2023 (www.fe.up.pt/ajp2023).

The aim of the conference is to provide a unique opportunity to exchange information, present the latest results and discuss issues relevant to advanced methods of joining such as friction stir welding, joining by plastic deformation, laser welding, advanced mechanical joining, adhesive bonding and hybrid joining. Emphasis is placed on process optimization in experimental and simulation terms, metallurgical and material behavior associated with joining, engineering properties and assessment of joints, health and safety aspects of joining, durability of joints in service, industrial applications and education.

Approximately 155 papers were presented by researchers from more than 25 countries. In order to disseminate the work presented at AJP 2023, selected papers were prepared, resulting in the present volume dedicated to advanced joining processes. A wide range of topics is covered, resulting in nine papers dealing with the latest research topics in mechanical joining (1st section), joining by plastic deformation (2nd section) and welding (3rd section). The book represents the state of the art in advanced methods of joining and also serves as a reference volume for researchers and graduate students working with advanced joining processes.

The organizers and editors would like to thank all the authors for their participation and cooperation in making this volume possible. Finally, I would like to thank the team of Springer-Verlag, especially Dr. Christoph Baumann and Ute Heuser, for the excellent cooperation during the preparation of this volume.

Paulo Martins would like to acknowledge the support provided by Fundação para a Ciência e a Tecnologia of Portugal and IDMEC under LAETA-UIDB/50022/2020 and PTDC/EME-EME/0949/2020.

December 2023

Lucas F. M. da Silva
Paulo Martins
Uwe Reisgen

Contents

Mechanical Joining (1st Section)

Evaluation of the Load-Bearing Behaviour of Bolts and Lockbolt Systems Under Combined Tension and Shear Loading

A. Holch, R. Glienke, M. Dörre, and K. M. Henkel

Abstract In this paper, experimental studies on the load-bearing behaviour of tensile test pieces, bolts, and lockbolts subjected to combined tension and shear loading are presented. The results are compared to the design approaches from different standards and evaluated in terms of reserves and uncertainties. In general, a notch-independent behaviour is observed for the specimens with smooth, threaded, or grooved shank. It turns out that the description of the load-bearing behaviour by linear interaction models is unreliable. Although the testing results are arranged in an arc shape in the interaction diagram, they are located on the uncertain side of the quadratic interaction model, which is valid according to the standard VDI 2230 part 1. Especially due to the lack of consideration of the tensile load-bearing capacity of the cross section in the shear plane, the load-bearing potential is not fully utilised by the interaction approaches of some standards.

Keywords Lockbolt system · Lockbolt connection · Bolted connection · Interaction resistance · Design rules

A. Holch (✉) · R. Glienke · M. Dörre
Fraunhofer Institute for Large Structures in Production Engineering (IGP), Albert-Einstein-Str. 30, 18059 Rostock, Germany
e-mail: alexander.holch@igp.fraunhofer.de

R. Glienke
e-mail: ralf.glienke@igp.fraunhofer.de

M. Dörre
e-mail: maik.doerre@igp.fraunhofer.de

R. Glienke
Department of Engineering, University of Applied Science in Wismar, Philipp-Müller-Straße 14, 23966 Wismar, Germany

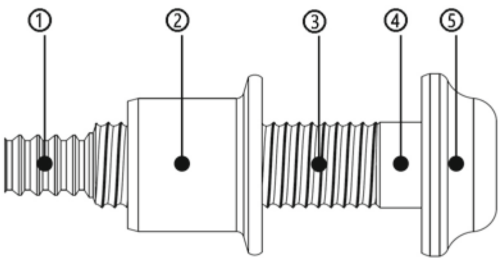
K. M. Henkel
Department of Mechanical and Naval Engineering, University of Rostock, Albert-Einstein-Str. 30, 18059 Rostock, Germany
e-mail: knuth.henkel@uni-rostock.de

L. F. M. da Silva et al. (eds.), *3rd International Conference on Advanced Joining Processes 2023*, Proceedings in Engineering Mechanics,
https://doi.org/10.1007/978-3-031-54732-4_1

1 Introduction

In the field of mechanical engineering, bolted connections are dimensioned according to the standard VDI 2230 Part 1 [1]. It is demanded that transverse loads are transmitted by friction grip. If this is not possible, the verification against shearing must be provided, as well as the interaction-verification for additional tension loads. Already existing studies [2, 3] for the application area of steel construction question the reliability of the quadratic interaction model. Therefore, within the framework of this paper, experimental investigations regarding the load-bearing behaviour of combined tension and shear tests will be presented and used to evaluate current interaction models.

As an alternative for traditional bolting assemblies, lockbolt fasteners (Fig. 1) can be used. The assembly of lockbolts is a torsion-free preloading by elongating the bolt, while the softer collar material is formed into the grooves of the bolt. Lockbolts are secured against self-loosening. More detailed information on technology of lockbolt systems can be found in DVS/EFB 3435-1 [4], see also [5, 6]. In contrast to the design principle of bolts (failure in the free loaded bolt thread), the failure mechanism of lockbolts is characterised by collar stripping. When subjected to single shearing load, bolts and lockbolts fail due to shear fracture in the shear plane. Both under tension load and under shear load, lockbolts have a higher load capacity than fully threaded bolts with the same strength grade and nominal size due to the larger tensile stress area. Since the load-bearing behaviour of lockbolts for combined tension and shear loading is currently unknown, a conservative interaction model is employed. Therefore, the higher individual load-bearing capacities compared to bolts do not come into effect. Within the framework of a publicly funded research project [7], experimental and numerical studies were carried out to address the lack of knowledge of combined tension and shear resistance and to develop an approach for the interaction verification of lockbolt systems. This paper focuses on experimental investigations.



1 Pintail
2 Collar
3 Locking grooves
4 Smooth shank
5 head

Fig. 1 Schematic drawing of lockbolt system [4]

2 State of the Art

2.1 Interaction Resistance of Bolting Assemblies

The influence of combined tension and shear loading regarding the load-bearing behaviour was investigated in 1987 by KNOBLOCH/SCHMIDT [8] to develop a design approach for steel construction for the first time. In a two-step test procedure, double shear tests were carried out on tension loaded round bars and threaded rods, which were subjected to various levels of tension loading. Based on the results, the quadratic interaction approach of the tension and shear utilisation considering the cross-sectional area in the shear plane was proposed and included in DIN 18,800-1 [9] and adopted in the guideline VDI 2230 Part 1 [10], see Table 1.

For the determination of the interaction equation in Eurocode 3 (EN 1993-1-8 [11]) the research conducted by SNIJDER et al. [12] was taken into account [13]. However, due to uncertainties in the results when compared to the quadratic interaction model, a bilinear interaction model was proposed. In favour of a uniform verification equation, it is neglected, whether the shank or the thread is located in the shear plane, see Table 1.

In response to the discrepancies between the quadratic and the bilinear interaction model, further investigations were conducted by RENNER/LANGE [2, 3, 14]. In contrast, these investigations involved applying the testing load at various angles to the bolt axis, allowing for the simultaneous application of tension and shearing loads. Compared to the quadratic interaction model, the experimental results are on the uncertain side, which is the reason why a correction is proposed, see Table 1. To facilitate the comparison of various design approaches, a consistent nomenclature is employed.

2.2 Interaction Resistance of Lockbolt Systems

The design of connections with lockbolt systems is carried out according to DVS-EFB 3435-2 [15], also referring to [16, 17]. The aim in developing this guideline was to provide a comprehensive verification procedure for connections in both steel construction and mechanical engineering for the user. Due to lack of knowledge about the load-bearing behaviour under combined tension and shear loading, the linear interaction model was agreed as a conservative assumption for lockbolts, as illustrated in Table 1.