

Copyrighted Material

WOODHEAD PUBLISHING SERIES IN WELDING AND OTHER JOINING TECHNOLOGIES



WELDING AND JOINING OF AEROSPACE MATERIALS

SECOND EDITION



Edited by
MAHESH CHATURVEDI

Copyright

Woodhead Publishing is an imprint of Elsevier

The Officers' Mess Business Centre, Royston Road, Duxford, CB22 4QH, United Kingdom

50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

The Boulevard, Langford Lane, Kidlington, OX5 1GB, United Kingdom

Copyright © 2021 Elsevier Ltd. All rights reserved.

No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher. Details on how to seek permission, further information about the Publisher's permissions policies and our arrangements with organizations such as the Copyright Clearance Center and the Copyright Licensing Agency, can be found at our website: www.elsevier.com/permissions.

This book and the individual contributions contained in it are protected under copyright by the Publisher (other than as may be noted herein).

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

Library of Congress Cataloging-in-Publication Data

A catalog record for this book is available from the Library of Congress

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library

ISBN: 978-0-12-819140-8 (print)

ISBN: 978-0-12-819141-5 (online)

For information on all Woodhead publications visit our website at <https://www.elsevier.com/books-and-journals>



Publisher: Matthew Deans

Acquisitions Editor: Carrie Bolger

Editorial Project Manager: Mariana L. Kuhl

Production Project Manager: Vijayaraj Purushothaman

Cover Designer: Vicky Pearson Esser

Typeset by SPi Global, India

Contributors

- A.C.Addison - TWI Ltd., Cambridge, United Kingdom
- M.M.Attallah - University of Birmingham, Birmingham, United Kingdom
- R.Benedictus - Delft University of Technology, Delft, The Netherlands
- I.Bhamji - TWI Ltd., Cambridge, United Kingdom
- S.Łłacha - Lukaszewicz - Institute of Welding, Gliwice, Poland
- J.Blackburn - TWI Ltd., Cambridge, United Kingdom
- A.Elrefaei - Dortmund University of Technology, Dortmund, Germany
- Richard Freeman - TWI Ltd., Cambridge, United Kingdom
- J.Hofstede - Delft University of Technology, Delft, The Netherlands
- P.Johnson - Liverpool John Moores University, Liverpool, United Kingdom
- A.Kwakernaak - Delft University of Technology, Delft, The Netherlands
- Ho-Sung Lee - Korea Aerospace Research Institute, Daejeon, Republic of Korea
- Gang Li - Aerospace Research Centre, National Research Council Canada, Ottawa, ON, Canada
- Min Liao - Aerospace Research Centre, National Research Council Canada, Ottawa, ON, Canada
- O.A.Ojo - Department of Mechanical and Manufacturing Engineering, University of Manitoba, Winnipeg, MB, Canada
- R.A.Pethrick - Deceased
- A.Phillips - Cambridge Vacuum Engineering, Denny Industrial Centre Pembroke Avenue Waterbeach, Cambridge, United Kingdom
- J.Poulis - Delft University of Technology, Delft, The Netherlands
- M.Preuss - University of Manchester, Manchester, United Kingdom | Monash University, Melbourne, VIC, Australia
- Guillaume Renaud - Aerospace Research Centre, National Research Council Canada, Ottawa, ON, Canada
- N.L.Richards - Department of Mechanical and Manufacturing Engineering, University of Manitoba, Winnipeg, MB, Canada
- P.L.Threadgill - TWI Ltd., Cambridge, United Kingdom (Retired)
- H.L.Tsai - Missouri University of Science and Technology, Rolla, MO, United States
- K.R.Vishwakarma - Department of Mechanical and Manufacturing Engineering, University of Manitoba, Winnipeg, MB, Canada
- P.C.Wang - General Motors Corporation, Alpharetta, GA, United States
- M.St.Wegłowski - Lukaszewicz - Institute of Welding, Gliwice, Poland
- T.T.Zhang - Taiyuan University of Technology, Taiyuan, China
- J.Zhou - Pennsylvania State University, The Behrend College, Erie, PA, United States

1. New welding techniques for aerospace materials

Richard Freeman - TWI Ltd., Cambridge, United Kingdom

Pages 1-19

- 1.1. Introduction
- 1.2. Airworthiness implications of new welding and joining technologies
 - 1.2.1. The use of friction stir welding (FSW) in the eclipse 500 aircraft
 - 1.2.2. The use of laser beam welding for Airbus aircraft
 - 1.2.3. The use of laser blown powder additive manufacturing for the repair of turbine seal segments
 - 1.2.4. The use of laser powder bed fusion additive manufacturing for the manufacture of the LEAP engine fuel nozzle
- 1.3. Future developments and trends
 - 1.3.1. Friction stir welding of aluminum alloys
 - 1.3.2. Friction stir welding of titanium and nickel alloys

- 1.3.3. Linear friction welding (LFW)
- 1.3.4. Hybrid laser arc welding
- 1.3.5. Reduced pressure electron beam welding
- 1.3.6. Electron beam texturing (EBT)
- 1.3.7. Reduced spatter MIG welding of titanium alloys
- 1.3.8. Additive manufacturing (AM)
- 1.4. Review of welding processes

References

Abstract

Aircraft have been manufactured for decades using of a wide variety of welding and joining techniques. There have been significant developments in techniques over the last 15–20 years, and this has also led to the adoption of even more appropriate and stringent non-destructive inspection methods.

Keywords

Friction welding, Titanium alloys , Steel, Laser beam welding, Turbine, Aerospace, Laser additive manufacturing, Linear friction welding, Friction stir welding

2. Inertia friction welding (IFW) for aerospace applications

M.M.Attallah - University of Birmingham, Birmingham, United Kingdom

and

M.Preuss - University of Manchester, Manchester, United Kingdom | Monash University, Melbourne, VIC, Australia

Pages 21-65

- 2.1. Introduction
 - 2.1.1. Process development
 - 2.1.2. Inertia friction welding (IFW) process description
 - 2.1.3. IFW process parameters
 - 2.1.4. IFW process stages
 - 2.1.5. IFW production machines
 - 2.1.6. Advantages and disadvantages of IFW
- 2.2. Process parameters, heat generation and modeling
 - 2.2.1. Process parameters and joint design
 - 2.2.1.1. Example
 - 2.2.1.2. Heat generation
 - 2.2.1.3. Analytical and numerical (finite-difference) modeling
 - 2.2.1.4. Thermal and thermomechanical modeling
- 2.3. Microstructural development
 - 2.3.1. Nickel-based superalloys
 - 2.3.2. Steels
 - 2.3.3. Titanium alloys
 - 2.3.4. Other alloys
- 2.4. Development of mechanical properties
 - 2.4.1. Ni-based superalloys

- 2.4.1.1. Microhardness development
- 2.4.1.2. Tensile properties
- 2.4.1.3. Fatigue-crack propagation (FCP)
- 2.4.2. Steels
 - 2.4.2.1. Microhardness development
- 2.4.3. Titanium alloys
 - 2.4.3.1. Tensile properties
 - 2.4.3.2. Fatigue properties
- 2.5. Residual stress development
- 2.6. Future trends
- 2.7. Source of further information and advice
- References

Abstract

The use of inertia welding in the aerospace industry has been steadily increasing owing to the significant improvements it provides in joint quality, compared with the use of fusion welding. This chapter introduces the process, with respect to its operation, parameters, differences from other friction welding techniques and equipment. It also explains the application of the technique and the selection of the process parameters, and the different mathematical, analytical and numerical approaches that are used to model the thermal fields and residual stress development. Details of the microstructural, mechanical properties and residual stress development in inertia friction-welded Ni-based superalloys, titanium alloys, steels and other alloys are also discussed.

Keywords

Inertia friction welding, Nickel superalloys, Titanium alloys, Steel, Finite element modeling, Microstructure, Residual stresses

3. Laser welding of metals for aerospace and other applications

J.Blackburn - TWI Ltd., Cambridge, United Kingdom

Pages 67-94

- 3.1. Introduction
- 3.2. Operating principles and components of laser sources—An overview
- 3.3. Key characteristics of laser light
- 3.4. Basic phenomena of laser light interaction with metals
 - 3.4.1. Absorption
 - 3.4.2. Conduction and melting
 - 3.4.3. Vaporization and plasma formation
- 3.5. Laser welding fundamentals
 - 3.5.1. Conduction-limited laser welding
 - 3.5.2. Keyhole laser welding
- 3.6. Laser weldability of titanium alloys
 - 3.6.1. Embrittlement
 - 3.6.2. Cracking
 - 3.6.3. Hydrogen porosity

- 3.6.3.1. Workpiece preparation
- 3.6.3.2. Shielding gas
- 3.6.3.3. Filler material
- 3.6.3.4. Processing porosity and its prevention
 - 3.6.3.4.1. Directed inert-gas jet
 - 3.6.3.4.2. Laser power modulation
 - 3.6.3.4.3. Dual-focus laser-beam configuration
- 3.7. Future trends
- 3.8. Sources of further information and advice
- References
- Laser sources

Properties of laser light

Laser materials processing

Abstract

Laser welding is a high-power-density fusion-welding process that produces high aspect ratio welds with a relatively low heat input compared with arc-welding processes. Furthermore, laser welding can be performed “out of vacuum” and the fiber-optic delivery of near-infra-red solid-state laser beams provides increased flexibility compared with other joining technologies. Consequently, laser welding may be considered as a principal candidate for the production of metallic aerospace components for high-performance environments. This chapter details laser technology and the laser-welding process, and reviews research concerned with the laser welding of titanium alloys.

Keywords

Laser, Welding, CO₂, Nd:YAG, Yb-fiber, Yb:YAG disc, Titanium, Absorption, Conduction, Vaporization, Keyhole, Aerospace, Airframe, Aeroengine

4. Linear friction welding in aerospace engineering

I.Bhamji, A.C.Addison, P.L.Threadgill - TWI Ltd., Cambridge, United Kingdom (Retired)
M.Preuss - University of Manchester, Manchester, United Kingdom | Monash University, Melbourne, VIC, Australia

Pages 95-122

- 4.1. Introduction to linear friction welding
- 4.2. History and major applications of linear friction welding
 - 4.2.1. Quality control systems for linear friction welding
- 4.3. Linear friction welding machines
 - 4.3.1. Linear friction welding machine operation
- 4.4. Macroscopic features of and defects in linear friction welds
- 4.5. Microscopic features of linear friction welds
- 4.6. Linear friction welding of titanium alloys
 - 4.6.1. Mechanical properties
 - 4.6.2. Weldability
 - 4.6.3. Microstructure
 - 4.6.4. Effects of welding parameters

- 4.6.5. Residual stresses
- 4.6.6. Texture
- 4.6.7. Modeling
- 4.7. Linear friction welding of nickel-based superalloys
 - 4.7.1. Mechanical properties and weldability
 - 4.7.2. Microstructure
- 4.8. Linear friction welds in other materials
 - 4.8.1. Steels
 - 4.8.2. Aluminum alloys and metal matrix composites
 - 4.8.3. Titanium and nickel aluminides
- 4.9. Conclusion
- References

Abstract

Linear friction welding is a solid-state joining process, which involves forcing a stationary part against one that is oscillating in a linear manner. The frictional heat generated at the interface between parts, together with the applied force, cause a plasticized layer to form, and toward the end of the joining process the parts are effectively forged together with some plasticized material remaining at the weld interface. The process is currently established as a niche technology for the fabrication of titanium-alloy bladed disc assemblies in aero engines, however development work is currently being undertaken to allow the process to be used in a wider variety of applications utilizing materials other than titanium alloys. Use of the process for near-net-shape manufacture of parts in high-value materials certainly seems a likely future application for the process. This chapter will cover relevant published work conducted to date on linear friction welding. The basics of the process will firstly be described followed by a description of the workings of linear friction welding machines and their operation. The chapter will then go on to give a detailed account of work done on the linear friction welding of titanium alloys, nickel-based superalloys and various other materials.

Keywords

Linear friction welding, Applications, Defects, Microstructure, Modeling

5. Hybrid laser-arc welding in aerospace engineering

J.Zhou - Pennsylvania State University, The Behrend College, Erie, PA, United States

T.T.Zhang - Taiyuan University of Technology, Taiyuan, China

H.L.Tsai - Missouri University of Science and Technology, Rolla, MO, United States

P.C.Wang - General Motors Corporation, Alpharetta, GA, United States

Pages 123-156

- 5.1. Introduction
- 5.2. Fundamentals of hybrid laser-arc welding
 - 5.2.1. Transport phenomena in metal (electrode, droplets, and workpiece) and arc plasma
 - 5.2.1.1. Conservation of mass
 - 5.2.1.2. Conservation of momentum
 - 5.2.1.3. Conservation of energy
 - 5.2.1.4. Conservation of species
 - 5.2.2. Transport phenomena in laser induced plasma

- 5.2.3. Electrical potential and magnetic field
 - 5.2.3.1. Conservation of current
- 5.2.4. Arc plasma and its interaction with metal zone (electrode, droplets, and weld pool)
 - 5.2.4.1. Heat transfer
 - 5.2.4.2. Force balance
- 5.2.5. Laser-induced recoil pressure and keyhole dynamics
- 5.2.6. Laser-plasma interaction and multiple reflections of laser beam in keyhole
 - 5.2.6.1. Inverse bremsstrahlung (IB) absorption
 - 5.2.6.2. Fresnel absorption
- 5.2.7. Radiative heat transfer in laser-induced plasma
- 5.2.8. Tracking of free surfaces
- 5.3. Hybrid laser-arc welding of aeronautical materials
 - 5.3.1.1. Hybrid laser-arc welding of magnesium and its alloys
 - 5.3.1.2. Hybrid laser-arc welding of titanium and its alloys
 - 5.3.1.3. Hybrid laser-arc welding of aluminum and its alloys
- 5.4. Future trends
- References

Abstract

This chapter first describes the origin and major characteristics of the hybrid laser-arc welding technique. Then, fundamentals of this welding technique, such as laser-plasma interaction, keyhole formation and collapse, weld pool dynamics, metal melting and solidification, etc., are elaborated. Finally, applications, current research and development, and future challenges and development of hybrid laser-arc welding of aeronautical materials such as magnesium, aluminum, and magnesium alloys are discussed.

Keywords

Hybrid laser-arc welding, Keyhole formation and collapse, Plasma, Heat and mass transfer, Droplet formation and impingement, Aluminum, Magnesium, Titanium

6. Electron beam welding—Techniques and trends

M.St.Weglowski, S.Błacha - Lukaszewicz - Institute of Welding, Gliwice, Poland

A. Phillips - Cambridge Vacuum Engineering, Denny Industrial Centre Pembroke Avenue Waterbeach, Cambridge, United Kingdom

Pages 157-198

- 6.1. Introduction
- 6.2. Electron beam welding
- 6.3. Characteristics of the electron beam welding process
- 6.4. Machines for electron beam welding and other processes
- 6.5. Standardization
- 6.6. Other application of electron beam welding
 - 6.6.1. Electron beam cladding and surface modification
 - 6.6.2. Hardening
 - 6.6.3. Alloying
 - 6.6.4. Electron beam rapid prototyping

- 6.6.5. Repairing technology
- 6.7. Trends in electron beam welding
- 6.8. Summary
- References

Abstract

Electron beam welding, despite a long history and widespread arc and laser technology, is still widely used in industry. The main applications for this high efficiency welding process are automotive, electronics, electrical engineering, aerospace and mechanical engineering industry. The technology ensures high-quality welded joints in structural metals in a wide range of thickness from 0.025 to 300 mm. It is also used for the production of films and coatings by deposition and surface modification. In the paper approximated examples of the use of the electron beam are given by the welding, rapid prototyping, texturing surface, cladding with wire and powder as well as alloying. It also provides information about the possible techniques that can be used during these processes and the trends in electron beam welding.

Keywords

Electron beam welding, Electron beam cladding, Surface modification, Electron beam machines, Quality control, Systems monitoring

7. Heat-affected zone cracking in nickel-based superalloys and the role of minor elements

O.A.Ojo, N.L.Richards, K.R.Vishwakarma - Department of Mechanical and Manufacturing Engineering, University of Manitoba, Winnipeg, MB, Canada

Pages 199-228

- 7.1. Introduction
- 7.2. Characteristics of crack-inducing intergranular liquid
 - 7.2.1. Re-solidification behavior
 - 7.2.2. Critical stress/strain level
 - 7.2.3. Stress relaxation by intergranular liquid
- 7.3. Formation of HAZ grain boundary liquid
- 7.4. Constitutional liquation of second phase particles in nickel-based superalloys
 - 7.4.1. Constitutional liquation of γ' precipitates
- 7.5. Role of minor elements on HAZ intergranular liquation cracking
 - 7.5.1. Effect of boron
 - 7.5.2. Effect of carbon
 - 7.5.3. Effect of sulfur and phosphorous
 - 7.5.4. Magnesium, zirconium, and the rare earths
 - 7.5.5. Combinational effects of several elements
 - 7.5.6. Heat treatment effect
 - 7.5.7. Segregation behavior of minor elements

References

Abstract

The formation of heat affected zone cracking in fusion-welded materials is a major concern in the design and manufacture of nickel-based superalloy welded assemblies. It is a general weldability problem that affects a large number of advanced highly alloyed cast and wrought nickel base superalloys, particularly, those strengthened by ordered L12 intermetallic Ni₃(Al, Ti or Ta) γ' precipitates. While the problem of fusion zone cracking is also encountered in many of these alloys, it does not pose as great a challenge as HAZ liquation cracking because it can be essentially managed effectively by proper selection of filler materials and appropriate welding procedures. HAZ liquation cracking is, however, more insidious since the factors and phenomena contributing to its occurrence are often related to the composition of the material and its microstructure, both of which have been optimized to achieve desirable high temperature base metal properties. The HAZ cracking in the superalloys is generally intergranular and it usually associated with the formation of liquid film on HAZ grain boundaries during welding. The inability of this film to accommodate thermally and/or mechanically induced stresses experience during cooling results in grain boundary microfissuring through decohesion along one of the solid-liquid interfaces on the grain boundary and, thus, it is sometimes referred to as liquation cracking, hot cracking or hot tearing. Liquid film stage is the common element in various manifestations of hot tear near the complete solidification point of metals. The cooling cycle of HAZ intergranular liquid is somewhat similar to the final stages of solidification of castings and fusion zone in welds, hence, to a first approximation, the criteria that govern weld solidification cracking can be adopted to explain liquation cracking in the HAZ of weldments, and these are considered in this chapter.

Keywords

Nickel-based superalloys, Welding processes, Heat-affected zone microfissuring, Heat treatments
Microstructure, Minor elements

8. Improvements in bonding metals for aerospace and other applications

A.Kwakernaak, J.Hofstede, J.Poullis, R.Benedictus - Delft University of Technology, Delft, The Netherlands

Pages 229-275

- 8.1. Introduction: Key problems in metal bonding
- 8.2. Developments in the range of adhesives for metal
 - 8.2.1. Modified phenolic adhesives
 - 8.2.2. Epoxy adhesives
 - 8.2.2.1. Modified epoxy adhesives
 - 8.2.2.2. Out-of-autoclave curing methods
 - 8.2.2.3. Automotive bonding
 - 8.2.2.4. Assembly bonding
 - 8.2.3. Polyurethane adhesives
 - 8.2.4. Methyl methacrylate adhesives
 - 8.2.5. Adhesives with high flexibility
 - 8.2.6. Improvements in temperature resistance of adhesives
 - 8.2.6.1. Glass transition temperature
 - 8.2.6.2. Overlap shear strength at elevated temperature
- 8.3. Developments in surface treatment techniques for metal

- 8.3.1. Surface treatment of aluminum alloys
 - 8.3.1.1. Etching processes for aluminum alloys
 - 8.3.1.2. Anodizing processes for aluminum alloys
 - 8.3.1.3. Conversion coatings for aluminum alloys
 - 8.3.1.4. Chromium-free anodizing treatments for aluminum
- 8.3.2. Surface treatment of steel and stainless steel
 - 8.3.2.1. Surface treatment of carbon steel
 - 8.3.2.2. Surface treatment of stainless steel
- 8.3.3. Surface treatment of titanium
 - 8.3.3.1. Etching and conversion treatments
 - 8.3.3.2. Anodizing surface treatments
- 8.3.4. Development of sol-gel surface treatment for aluminum, steel and titanium
- 8.3.5. Developments in bonding primers
- 8.4. Developments in joint design
 - 8.4.1. Shear stress distribution of bonded overlap joints
 - 8.4.2. Effect of joint geometry, material and type of adhesive for lap joints
 - 8.4.3. Eccentricity in overlap joints
 - 8.4.4. Joint optimization
 - 8.4.5. Adhesive-bonded laminates
 - 8.4.6. Fiber metal laminates (FMLs)
 - 8.4.7. Weight and cost reduction
 - 8.4.8. Sandwich structures
 - 8.4.9. Bonded repairs
 - 8.4.10. Bonded window frames
- 8.5. Developments in modeling and testing the effectiveness of adhesive-bonded metal joints
 - 8.5.1. Analytical solutions
 - 8.5.2. Numerical tools
 - 8.5.3. Failure load prediction
 - 8.5.4. Fracture mechanics approach
 - 8.5.5. Improved analytical methods for fatigue-crack-growth prediction in FML
 - 8.5.6. Testing adhesive-bonded joints
 - 8.5.7. Determination of bondline strains by fiber-optic sensors
 - 8.5.8. Development of optical digital video microscopy to measure bondline strains
- 8.6. Future trends
- 8.7. Sources of further information and advice
- References

Abstract

This chapter discusses the developments in materials, processes and design, which make adhesive bonding an efficient and durable joining technology for metal structures. The chapter reviews the developments in adhesives and surface treatments for metal-bonded joints, which have improved the mechanical properties and processing characteristics, as well as significantly enhanced durability under humid or corrosive environments. Developments in joint design are discussed, from simple lap joints to complex bonded metal laminates. Further improvements in modeling and testing techniques are reviewed, which have led to more accurate prediction and determination of joint strength and durability.

Keywords

Metal-bonded joints, Surface treatment of metallic substrates, Durability, Joint design, Strength prediction

9. Composite to metal bonding in aerospace and other applications

R.A.Pethrick - Deceased

Pages 277-303

Acknowledgments

9.1. Introduction

9.1.1. Peculiarities of composite-metal bonding

9.2. Testing of adhesive bonded structures

9.2.1. Characterizing the strength of an adhesive

9.2.2. How is a good adhesive bond created?

9.2.3. Importance of the interface

9.3. Bonding to the metal substrate

9.3.1. Aluminum pretreatment

9.3.2. Titanium-alloy pretreatment

9.3.3. Primers

9.4. Composite pretreatment

9.5. Bonding composite to metal

9.6. Adhesives

9.6.1. Thermoset resins

9.6.2. Epoxy and polyimide adhesives

9.6.3. Hot-melt adhesives

9.6.4. Acrylic-based thermoplastic adhesives

9.6.5. Cyanoacrylate adhesives

9.6.6. Polyimide adhesives that cure by addition

9.6.7. Other reactive adhesives

9.6.8. Bismaleimide (BMI) adhesives

9.7. Composite-metal bonded structures

9.7.1. Manufacturing of metal-composite and metal/fiber laminate (MFL) structures

9.7.2. Effects of the environment on aging of MFLs

9.7.3. Metal-composite structures in repair situations

9.7.4. Nondestructive testing (NDT) of metal-composite structures

9.8. Conclusions

References

Abstract

The problem of bonding composite structures to metals is the main focus of this chapter. The bonding of composite to a metal creates two important issues. First, the problem of differences in the thermal expansion coefficient of the composite and the metal, and second, the differences in treatment of the substrates to ensure the development of good interfacial strength. This chapter considers appropriate processes for the preparation of the surfaces of the metal and composite prior to bonding and also the

selection of the resin system. The topics of environmental aging and nondestructive testing are briefly considered.

Keywords

Metal-composite bonding, GLARE, Fatigue and environmental aging, Nondestructive testing, Surface pretreatment

10. Diffusion bonding of metal alloys in aerospace and other applications

Ho-Sung Lee - Korea Aerospace Research Institute, Daejeon, Republic of Korea

Pages 305-327

- 10.1. Introduction
- 10.2. Diffusion-bonding process
 - 10.2.1. Titanium alloys
 - 10.2.1.1. Titanium lightweight honeycomb panels
 - 10.2.1.2. Attitude control pressurant vessel
 - 10.2.1.3. Hollow fuel tank
 - 10.2.2. Steel and copper alloy
 - 10.2.2.1. Combustion chamber with cooling channels
- 10.3. Conclusions and future trends

References

Abstract

Diffusion bonding is a solid-state bonding process. The metal components being joined undergo only microscopic deformation, and the joining region is homogeneous—without secondary materials or liquid phases. This chapter investigates diffusion bonding of titanium, steel and copper alloys used in the fabrication of several aerospace components with various complex configurations. The result shows that the diffusion-bonding method can be successfully used with blow forming to form near-net-shape aerospace components, including high-pressure tanks for attitude control of spacecraft, a combustion chamber with copper cooling channels and lightweight structural panels.

Keywords

Diffusion bonding, Solid-state bonding, Diffusion welding, Aerospace, Lightweight

11. High-temperature brazing in aerospace engineering

A.Elrefaey - Dortmund University of Technology, Dortmund, Germany

Pages 329-362

- 11.1. Introduction
- 11.2. Filler metals
 - 11.2.1. Nickel-based filler metal
 - 11.2.2. Silver-based filler metal
 - 11.2.3. Titanium-based filler metal
 - 11.2.4. Gold-based filler metal
 - 11.2.5. Palladium-based filler metal
 - 11.2.6. Cobalt-based filler metal

- 11.3. Trends in brazing at high temperature
 - 11.3.1. Transient liquid phase bonding process
 - 11.3.2. Rapidly solidified amorphous filler metal
 - 11.3.3. Self-propagating high-temperature systems
- 11.4. Conclusion and future trends

References

Abstract

High-temperature brazing in aerospace engineering is gaining much more attention day by day. The process usually takes place in a vacuum furnace or controlled atmosphere at above 900 °C to create high-strength bonds with good corrosion and oxidation resistance. This chapter reviews commonly used brazing filler metals such as nickel, silver, titanium, gold, cobalt, palladium alloys and the new developing alloys in this field. The chapter additionally highlights the processes/techniques for brazing and equipments together with the novel innovation in this topic and the new trends in brazing at high temperature as well. There is particular emphasis on self-propagating high-temperature systems, transient liquid-phase bonding and rapidly solidified amorphous filler metals.

Keywords

Brazing, Aerospace, Engineering, Filler metal, High-temperature

12. Quality control and nondestructive testing of self-piercing riveted joints in aerospace and other applications

P.Johnson - Liverpool John Moores University, Liverpool, United Kingdom

Pages 363-381

- 12.1. Introduction
 - 12.1.1. Nondestructive testing (NDT) techniques
- 12.2. Computer vision
 - 12.2.1. Rivet status
 - 12.2.2. Rivet orientation
 - 12.2.3. Material measurement
 - 12.2.3.1. Side material measurement
 - 12.2.3.2. Top material measurement
 - 12.2.3.3. Rivet head position
 - 12.2.3.4. Rivet button diameter
- 12.3. Ultrasonic testing
 - 12.3.1. Self-piercing rivet
 - 12.3.2. Riveted joint
- 12.4. Conclusion

References

Abstract

Self-piercing riveting (SPR) has become a significant joining technique for the automotive and aerospace applications of aluminum sheets. Quality control in this locale has progressed at an altogether more leisurely rate than other areas of mechanical joining (e.g. spotweld) and is underdeveloped. Testing the quality mechanical interlock is often achieved by destructive testing, which results in material and time

wastage. The solution is online monitoring of the self-piercing riveting process to provide nondestructive testing of the mechanical interlock. Introducing sensors into the process facilitates real time data acquisition, which can be used to determine the quality of the joint.

Keywords

Self-pierce riveting, SPR, Rivets, Nondestructive testing, NDT, Computer vision, Image processing, Ultrasound, Narrowband, Ultrasonic testing, NBUS

13. Assessing the riveting process and the quality of riveted lap joints in aerospace and other applications

Gang Li, Guillaume Renaud, Min Liao - Aerospace Research Centre, National Research Council Canada, Ottawa, ON, Canada

Pages 383-426

Acknowledgments

- 13.1. Introduction
- 13.2. Riveting process and quality assessment of the rivet installation
 - 13.2.1. Solid rivets
 - 13.2.2. Preparations of riveting process and quality assessment
- 13.3. Determination of residual strains and interference in riveted lap joints
 - 13.3.1. Experimental measurements
 - 13.3.2. Finite element methods
- 13.4. Summary and recommendations for the riveting process research
- 13.5. Case study using the force-controlled riveting method
 - 13.5.1. Case study 1: Effect of the riveting process on residual stress/strain in joints
 - 13.5.1.1. Joint and materials
 - 13.5.1.2. Measurements
 - 13.5.1.3. Numerical simulation
 - 13.5.1.4. Results and summary
 - 13.5.2. Case study 2: Stress condition in three-row countersunk riveted lap joints
 - 13.5.2.1. Experimental aspect
 - 13.5.2.2. Three-dimensional FE modelling
 - 13.5.2.3. Comparisons of the experimental and FE results
 - 13.5.2.4. Parametric study using the validated 3D FE model
 - 13.5.2.5. Results and summary
 - 13.5.3. Case study 3: Fatigue life assessment for three-row countersunk riveted lap joints
 - 13.5.3.1. Experimental aspect
 - 13.5.3.2. Prediction of the fatigue life and further crack growth
 - 13.5.3.3. Results and discussion
 - 13.5.3.4. Commentary on the study of fatigue life assessment
- 13.6. Concluding remarks and future work

References

Abstract

This chapter first reviews several aspects of the riveting process to ensure that riveted joints will have excellent fatigue performance. These aspects include solid rivets, joint design rules, several experimental and numerical methods to determine the residual stress/strain and interference in riveted joints, and the current approach for studying the riveting process. It then provides three case studies using experimental and finite element methods to assess: (i) the effect of the riveting process on the residual stress/strain in joints, (ii) the stress condition in riveted lap joints when the joints are remotely loaded in tension, and (iii) the fatigue life using an analytical methodology. Concluding remarks and future work on potential development directions for riveting tools, rivets, and riveted-bonded attachment method are briefly provided.

Keywords

Finite element, Fatigue life, Riveted lap joint, Residual stress/strain, Rivet squeeze force, The Smith-Watson-Topper (SWT) equation

14. Failure of joints in service

Richard Freeman - TWI Ltd., Cambridge, United Kingdom

Pages 427-435

- 14.1. Introduction
- 14.2. DeHavilland Comet crashes
- 14.3. General Dynamics F-111 crash
- 14.4. Dan Air Boeing 707 crash
- 14.5. Aloha Airlines Boeing 737 accident
- 14.6. United Airlines DC10 accident
- 14.7. The importance of international standards

Reference

Further reading

Abstract

While media coverage of an air accident is very dramatic and is invariably associated with the loss of lives, the number of air accidents has been steadily decreasing over the last 30 years (Aviation Safety Network 2017 statistics) and air travel is considered to be the safest form of travel. In 1998 the International Civil Aviation Organisation (ICAO) established a universal safety oversight audit programme, comprised of regular, mandatory, systematic and harmonized safety audits to be carried out by ICAO on all Contracting States. Since 1 January 1999, the Safety Oversight Audit (SOA) Section of the Air Navigation Bureau of ICAO has been conducting safety oversight audits of the civil aviation authorities of member countries in relation to personnel licensing, operation of aircraft, and airworthiness. The audits are designed to determine the status of States' implementation of the critical elements of a safety oversight system and the implementation of relevant ICAO Standards and Recommended Practices, associated procedures, guidance material and safety-related practices. In addition, in March 2006 the EU published a Community list of air carriers subject to an operating ban within the European Community. Bans and operational restrictions are only imposed based on evidence of violation of objective and transparent criteria. These criteria focus on the results of checks carried out in European airports; the use of poorly maintained, antiquated or obsolete aircraft; the inability of the airlines to rectify shortcomings

identified during inspections; and the inability of the authority responsible for overseeing an airline to perform its task properly. Member States reported that five countries have an inadequate system for regulatory oversight. One important consequence of the black list will be to root out the practice of flags of convenience whereby some countries issue Air Operation Certificates to dubious airline companies (Aviation Safety Network safety assessment information).

Keywords

Air accident, Safety audits, Comets, Guidelines, Eddy current, Corrosion

15.Index