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1. New welding techniques for aerospace materials

Richard Freeman - TWI Ltd., Cambridge, United Kingdom

Pages 1-19

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

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Pages 21-65

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

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

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

Pages 95-122

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

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Pages 123-156

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

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Pages 157-198

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

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Pages 199-228

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

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Pages 229-275

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

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

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

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Pages 329-362

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

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

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Pages 383-426

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

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Pages 427-435

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

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