

Structural Connections for Lightweight Metallic Structures

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Preface

Increasing concern with fuel consumption leads to widespread interest in lightweight structures for transportation vehicles. Several competing technologies are available for the structural connections of these structures, namely welding, mechanical fastening/riveting, and adhesive technologies.

Arranged in a single volume, the intention of this book is to present state-of-the-art discussions of those aspects and processes presenting greater novelty whilst simultaneously keeping wide applicability potential and interest. It is therefore not intended to substitute the existing comprehensive treatments dealing with each technology, as (da Silva et al. 2011) or (Grote and Antonsson 2009).

Riveting is the traditional aeronautical process for joining Aluminium alloy fuselage components. Although there is growing interest in the use of composites for aerostructures, it is likely that Aluminium alloy fuselage construction will still be used at least for certain sizes of aircraft, and certainly knowledge of the ageing behaviour of the vast existing fleet will continue to be needed in the next decades. For these reasons, the book will address specific problems of riveted joints, including the statistical treatment of multiple site damage, and the behaviour of cracks growing from fastener holes.

Great interest is dedicated to welding of lightweight structures, particularly because of economic reasons derived of part count reduction, faster and cheaper fabrication, and possible weight gains. However, drawbacks of welding include variation of properties in the weldment area, intrinsic metallurgical difficulties possibly leading to unacceptable defects, as well as, from a mechanical design point of view, possibly detrimental fatigue behaviour features associated with the continuous path for crack propagation. Currently, the technological processes receiving more widespread interest in metallic lightweight structures are laser beam welding (LBW) and friction stir welding (FSW) and the book discusses both thoroughly, including novel structural designs and applications. Also, a chapter concerning manufacturing cost assessment of friction stir welded structures in the aeronautical context, compared with the traditional riveting process, is included.

Aeronautical and automotive manufacturers dedicate increasing attention to adhesive joining technologies, because of potential cost and weight savings, associated with excellent capability for geometrical precision because, unlike in welding, no great temperature variations are involved in the fabrication of adhesive bonded components. Among current drawbacks preventing more widespread application in industry that will be discussed in detail, are durability concerns as well as specific problems of stress concentration at the end of overlap joints.

The topics chosen for coverage in this book have the common feature of being currently applied in lightweight metallic structures, and one of the characteristics of this work is bringing together relevant state-of-the-art information usually presented in separate publications specializing in a single technology.

New aircraft designs and new propulsion systems are under continuous development, with new materials and new manufacturing processes playing an important role in the improvement of air transportation efficiency. This continuous development leads to significant fuel savings, and lower operational costs. Design concepts for aircraft must also pass stringent performance criteria that impose minimum values of weight. Aeronautical designs rely on damage tolerance principles, e.g. (Schmidt 2003). There has always been a drive to reduce aircraft weight, and, simultaneously, an appreciation that lightweight designs can be too costly. Indeed, as noted by (Emero 1967) minimum-weight designs are frequently too costly to manufacture, whereas less expensive and easy to fabricate and assemble designs are often much heavier. The most efficient design on the basis of both cost and weight often lies between these two extremes.

The present book gives a contribution to these everlasting discussions, of which some past steps are documented in publications of archival or historical significance.

In the case of automobile engineering, an early paper (O’Gorman 1908) wisely states that *‘when we come to consider particular parts, pistons, connecting rods, or body weight, we shall find that every single item is so full of suggestiveness that no man can write more than a brief essay on motor car weights if he has anything else to do’*. Later, discussing weight savings in automobiles, (Ferrier Brown 1923) notes that *‘the keynote of success in weight reduction is attention to detail. Every ounce that can be spared should be cut out, provided it is a straightforward machining operation. Weight saving may not mean economy in the sense that first cost will be substantially reduced, but it will certainly prove a true and continuous economy in running costs and extended life of the vehicle’*. After this early manifestation of concern with the life-cycle cost of a product, the mentioned paper goes on to note that *‘considerable saving in weight can be effected by using aluminium for the panels instead of steel, though they are not so robust as steel panels, have not the same high physical properties, and do not offer the same facilities for welding’*. As shown by (Pomeroy 1939) discussing the use of aluminium in automobile design, cost is a ubiquitous object of concern. The abundance of literature on the subject precludes further reference to the past, but, nevertheless, (Kewley 1987) and (Allen 1994) may be cited for comprehensively

discussing cost implications of Al and adhesive technology in automobile manufacturing, and of the use of Ti as means to save weight in automotive engines, respectively.

In the case of railways, (Thring 1954) and (Brockway 1959) discuss the implications of the use of Al instead of steel in railway passenger cars, whereas (Mills 1939) *‘describes a new (welded) design for a steam locomotive frame of plate type, and draws comparisons with the corresponding design for riveted construction, showing important economies in cost and in weight’*. Further on in that paper, the author states that *‘much attention has been given of late years to the question of residual stresses in welded structures and methods of stress relief’*, cogently illustrating that certain subjects keep resurfacing, albeit in different circumstances and environments, as the present book will once again show.

This book is composed by ten chapters covering the topics described above. A brief description of each chapter is now presented:

Chapter 1—Assessment of Multiple Site Damage in Riveted Aircraft Joints

Multiple Site Damage (MSD) and Widespread Fatigue Damage (WFD) are typical effects which may occur in structures of aging aircraft. They consist in the development of scenarios of sets of small cracks, which interact at a certain stage and may suddenly burst into one large crack. The chapter summarizes the approach used in a number of European companies for the assessment of the susceptibility to WFD as well as by some European researchers today. In addition, an approach to interpret data from these probabilistic analyses with respect to the criticality of designs is proposed.

Chapter 2—Laser Welding of Structural Aluminium

The chapter presents an overview, characteristics and progresses of the fusion welding processes used in aluminium welding.

Laser sources for welding have been available for a few decades but new concepts are coming to the market. The chapter addresses the most commonly used lasers for materials processing and their interaction with aluminium alloys in welding applications. More recent laser types are also included, namely fibre lasers and disc lasers as, though only more recently available in the market, their potential is foreseen as being interesting for welding of aluminium.

Chapter 3—Laser Beam Welding and Automotive Engineering

This chapter gives an overview of the use of laser welding on automotive industry, which is the main industrial sector for its application. Laser welding permits the use of significant improvements in lightweight structures manufacturing for the automotive industry, as the use of tailor welded blanks. The main features of the laser welding process and breakthroughs achieved by the use of laser welding in the automotive industry are summarized.

Chapter 4—State-of-the-Art in FSW Technologies

The Friction Stir Welding (FSW) is currently considered an important development in welding technology, saving costs and weight for a steadily expanding range of applications of lightweight metallic structures. Evidences of the disruptive character of the FSW process are the prompt adoption by world-wide industry of the significant advantages of FSW and the numerous technic-scientific papers and patents published.

In this chapter, some of the basic fundamentals underpinning the invention of FSW technology are presented with emphasis on the concept of the third-body region. The Non-Destructive Testing assessment of the most relevant imperfections in FSW is discussed for butt and lap joints.

Chapter 5—FSW of Lap and T-Joints

Even if in the last years several researches have studied the Friction Stir Welding (FSW) process, it should be observed that most of these studies are concerned with the butt joint and just a few of them extend to more complex geometries. The acquired knowledge on FSW process of butt joints is not immediately extendable to lap and T-joints.

The chapter is focused in the development of FSW process for its application to lap and T-joints. As an example, in lap and T-joints a major vertical component of the material flow is required to obtain sound joints. Furthermore, in the FSW of T-parts a proper clamping fixture is needed in order to fix the stringer during the process. The tool geometries together with the tool feed rate and rotating speed must be determined in order to get an effective material flow and bonding conditions during the FSW process.

Chapter 6—Lightweight Stiffened Panels Fabricated Using Emerging Fabrication Technologies: Fatigue Behaviour

The need for lower cost and the emergence of new welding technologies has brought interest in large integral metallic structures for aircraft applications; however, new problems must be addressed, e.g. in integral structures, a crack approaching a stiffener propagates simultaneously in the skin and into the stiffener and breaks it. The use of manufacturing techniques such as high speed machining (HSM), laser beam welding (LBW) and friction stir welding (FSW) requires further experimental and numerical work concerning the fatigue behaviour of panels manufactured using those processes.

The chapter is focused on an experimental test programme including fatigue crack growth rate characterization in panels fabricated using HSM, LBW and FSW.

Chapter 7—Damage Tolerance of Aircraft Panels Taking into Account Residual Stress

The chapter seeks to summarize the ideas of damage tolerance of aircraft panels, keeping in mind the effect of residual stresses. First, concepts and techniques are briefly reviewed, and afterwards their application to experimental work is discussed.

As a result of the traditional usage of riveted joints in the aluminium alloy fuselage of civil aircraft, one advantage of this type of joints is the existing experience concerning their design and maintenance. Alternatives to riveting are being considered aiming at economies in fabrication time, cost and weight. However, open issues concerning the use of integral structures in aeronautics include the damage tolerance problem, since the integral nature of the structure provides a continuous path for crack growth. A topic of the chapter is the fatigue behaviour of integral stiffened panels focusing on the influence of residual stress fields.

Chapter 8—Multi Material Adhesive Joining in the Automotive Sector

Technological progress over the last decade has provided the automotive industry with more flexibility in terms of design and manufacturing. Automotive manufacturers face conflicting requirements regarding environmental legislation and an increasing demand for safety and on-board equipment which tends to increase the overall vehicle weight and fuel consumption. This challenge has led to the increased use of lightweight materials to replace conventional steel parts and structures. The chapter is intended to provide an overview of the materials, technologies and associated processes used to manufacture Aston Martin's vehicle bodies.

Chapter 9—Welded Aeronautical Structures: Cost and Weight Considerations

Product development is limited by engineering design capabilities. Engineering design is one of the most important phases during the development of a new product, particularly in the case of complex and safety-critical systems, in order to consider all safety concerns, e.g. in aircraft and nuclear power plants. In these cases, the introduction of new design concepts and solutions is tightly tapered by existing materials and manufacturing processes. In this chapter, a breakthrough joining process—friction stir welding (FSW) is discussed from the point of view of manufacturing costs.

Chapter 10—Materials Selection for Airframes: Assessment Based on the Specific Fatigue Behavior

Structural weight reduction is a major driver to improve the transportation efficiency. However, minimum-weight designs are frequently too costly to manufacture, whereas less expensive and easy to fabricate and assemble designs are often much heavier. Composite materials have high specific strength, are less

prone to fatigue crack initiation and provide enhanced flexibility for structural optimization compared to the aluminum alloys. On the other hand, aluminum alloys display higher toughness and better damage tolerance in the presence of defects. In order to improve the material selection and the comparison of airframe materials, [Chap. 10](#) presents a weight assessment based on the specific weight for different damage scenarios.

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