Volume 4: Materials Technology

Volume 4, comprises four Parts 18 – 21: 'Structural Materials', 'High Temperature Materials', 'Active Materials' and 'Materials for Space Applications'.

Part 18, 'Structural Mechanics', lays a sound and thoughtful foundation on the ongoing transition 'from metals to composites'. The first chapter does not begin with a celebration of metals, as one might expect, but with a stern reminder of our unsustainable reliance on cheap and plentiful oil. Numerous graphs are provided in support of this view. It is on a most positive note that the authors look to the future. First they confidently believe that 'a scarcity of cheap energy will (inevitably) become a stimulus for new technological developments', developments which they liken to the miniaturisation of 'systems' and dematerialisation of structures. They (the authors) also enthuse about what they see as a 'tremendous leap in morphologies' – a generous helping of which forms the 'meat' in subsequent chapters. A further argument to which the authors subscribe is that: 'Since 1960 most aircraft efficiency improvements (have) come from technological developments outside the realm of aircraft materials, structures and manufacturing', the improvement coming from the reduction of specific fuel consumption, made possible by the development of advanced turbofan propulsion units. Material scientists/engineers who choose to skip all this should home-in on the boxed sections of pages 2058-2059.

The case for using and continuing to use aluminium alloys and titanium alloys, where appropriate, is well put in Chapters 173-176, where metallurgical details and a host of processing techniques are discussed. Titanium alloys are further considered in Part 19, Chapters 189 and 190. But, for some odd reason, steel in its stainless, maraging and other alloy forms gets not a mention.

The thrust towards composites and the basics of composite structures begins with fibre-reinforced polymer composites, load bearing laminates (with some mathematics) and practical aerospace pressure vessel examples.

The science and technology of composite structures is further developed in Chapters 180-188. Subjects covered include: textile matrix composites: polymer matrix composites/ceramic matrix composites: 3D translaminar and textile reinforcements – areas of interest many. Chapter 183 on lightweight sandwich structures is likewise composite based, and wholly restricted to glass, graphite and aramid (fibre) skins, in woven or non-woven forms – all with organic/metallic/inorganic continuous/macrocellular/reinforced/unreinforced supporting cores.

Readers interested in manufacturing methods will find Chapter 184 on the nature and use of lasers for welding and drilling most informative. Although these processes are described as 'very complicated' they are capable of delivering high precision. Laser shot peening, laser cladding and direct metal deposition are other advanced techniques described.

A sound but fairly basic assessment of metal-to-metal and metal-to-composite bonded and bolted structural joints is given in Chapter 185, followed by Chapter 186 'Thermal Protection Systems (TPSs)', as used on the Space Shuttle orbiter, with an appraisal of hot structure – very cooled structure, in Chapter 186, where 'newer tile and blanket concepts', metallic heat shields and structurally integrated ceramic matrix composite solutions are discussed.

Chapter 187 'Advanced Composites made by the Layer-by-Layer (LBL) Assembly of Nanomaterials' contains much state-of-the-art material of interest to many. Suffice to say; inorganic, organic, polymeric and biological materials are used – clays, primarily layered

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silicates among them. The technique described entails 'the alternate disposition of oppositely charged components, layered into sheets, each layer being approximately 0·95mm thick by tens of thousands of nanometres wide'. The final chapter of Part 18 outlines the mechanical behaviour of nanomaterials in general.

Part 19 'High Temperature Materials', comprises eleven fact-packed chapters. Titanium alloys used in their ambient temperature role, in landing gear for example, are covered in Part 18. Their use in aeroengine applications at temperatures up to 600°C is well-documented here. Both Parts 18 and 19 provide much valuable information and insight into metallurgical, strength, performance and processing issues.

Titanium aluminide intermetallic (gamma phase) alloys are praised for their outstanding thermo – physical properties: high temperature oxidation resistance, low expansion and non-burn gas flow properties. All are characteristics which make them potentially suitable for aft stage compressor applications – possibly as replacements for Inconel nickel based alloys.

Metal Matrix Composites (MMCs) and Intermetallic Matrix Composites (IMCs) are championed in Chapters 190 and 191, where their potential roles in fan, turbine, exhaust locations in military engines and within the compressor, turbine and nozzle of civil aircraft engines is mapped. See Fig. 1, page 2308. More excellent cutaway drawings are reproduced on pages 2320 and 2321. Polycrystalline nickel-based superalloys get a fair hearing in Chapters 192 and 193 and are likely to be with us for years to come, albeit their melting point is 'only' 1350°C. The point is therefore made that in order to increase turbine efficiency, higher turbine entry temperatures (TETs) and hence higher melting point materials are required.

The author of Chapter 194

Beyond Nickel-Based Superalloys', suggests that Refractory Transition Metals (RTMs), such as niobium-silicide and molybdenium-silicide, which have melting points about 2,000°C warrant further development.

A few manufacturing processes relating to titanium alloys are considered in Chapter 195. Solid-state welding: Inertia Friction Welding (IFW) and Linear Friction Welding (LFW) are the favoured methods – claimed to yield lower residual stresses and offer the possibility of joining dissimilar metals.

The next two chapters on superplastic forming/diffusion bonding and near net shape forming are rightly paired. Both Chapters give metallurgical, strength and processing details, the Chapters being well-illustrated with real life examples. The nacelle frame and wide chord fan blades from Trent 900 provide impressive support. Other topics discussed include: direct laser deposition and Hot Isostatic Pressing (HIP), with thermal barrier coatings considered in a subsequent chapter.

Part 19 concludes with an appraisal of lifting and component classification. The final message being that lifting methods are conservative but justified by the time and huge expense incurred during design, manufacture and certification processes.

Part 20 'Active Materials Comprises' only five chapters but much that is written will come as news to many. Most likely readers will have heard of smart materials and shape memory alloys without knowing much about them. Electroactive ceramics, electroactive polymers, magneto materials and magneto rheological fluids number among the topics discussed. The two earliest credits are Olsen 1956 and Clauser 1968 but the main body of text is bang up to date. Air vehicle noise/vibration suppression as applied to rotorcraft, buffeting and flutter are examples cited of current use.

An extensive table of currently available hardware is presented on page 2420, along with several highly informative photos, one a wind tunnel model of a UCAV (unmanned combat air vehicle), courtesy of Northrop Grumman Corporation, which shows a conformal control surface under test.

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With regard to 'Ferroelectric Materials', Chapter 201, the reader is informed that 'ferro' does not allude to chemical composition, as most ferro electrics do not contain iron. The materials, whatever they are, possess the useful property referred to as 'spontaneous electrical polarisation' – a property which makes them suitable for switching applications.

Piezoceramic actuators and sensors are topics discussed in Chapter 202, and examples of adaptive or shape memory alloys given in Chapter 203, the most prominent of these being a 'cold flow/open, hot flow/closed' automatic (SMA) valve. This example is followed by a 'deep space device' known as a frangibolt, described as a small precompressed (SMA) heat responsive, notched bolt which fractures with heat and enables solar panels to be deployed. The future use of electroactive polymer (EAP) actuators concludes Part 20.

Part 21'Materials for Space Applications' begins at Chapter 205, with a few pages on the space environment. There is no reference to the layered near Earth atmosphere, but conditions between 300-30,000km and beyond are fully covered. Nine mission/payload types of satellites are listed, some in near circular orbits, others whirling around in highly eccentric elliptical paths, apogee 30,000km, perigee 200km, in the example given. It should come as no surprise to read that conditions in space are far removed from conditions on Earth, but the host of facts given is informative. Vacuum pressures as low as 10-15pa, close to and exceeding the vapour pressure of many materials is a hazard likely to cause gassing. The effect of atomic oxygen (AO) and other gases encountered in low orbit also present a problem and constitute a recurrent theme. In higher geosynchronous orbits; weather, navigational and communication satellites are exposed to the impact of micro meteoroids, ultra violet light and soft X-ray radiation. No less disturbing is the ongoing build-up of sizeable man-made debris, the growth rate of which is fully documented. According to NASA the anti-satellite experiment undertaken by China in 2007 added 2,200 objects of 5cm and more to the 13,000 known bits of debris already there.

The first material requirement is that the structure and equipment survives the extremely high gravitational forces, vibration and high temperatures during the launch. The second requirement is that the satellite surface is corrosive resistant and micro meteoroid durable in the longer term. While craft designed for re-entry need to be robust with foolproof thermal protection. The development of thermal insulation used on the Shuttle is rightly acknowledged as a major materials achievement.

Chapter 206 'Polymers in Space' is by a Russian author who has much to say about the mechanical, thermal and low specific weight properties of materials which are widely used. Polyamide Fluorinated Ethylene Propylene (FEP), Perfluorinated Polymers (PTFE), glass fibre 'Betacloth', impregnated with Teflon, Multi-Layer Insulation (MLI) enamels, used to cover the outer surfaces of spacecraft, to name but a few. The thermal optical properties of Kapton and the mass loss of thermal control paints are considered in Chapter 207, along with an article on the surfex and carbosurf processes.

The effect of micrometeoroid and orbital debris impact damage is well-documented in Chapter 208, and fully supported by articles on risk assessment procedures, protective shields and probability laws. Corrosion with a bit of mathematics follows in Chapter 209. Experimental procedures, projects and chronological events are discussed in Chapters 210 and 211. The first of these covers experiments conducted in space. The second describes equipment, simulations and more general aspects of ground based laboratory activity. Highlights include: Skylab, Space Shuttle and the *Mir* Space Station (*Mir*).

One final word: the books cannot be purchased separately and the full set of nine is prohibitively expensive. Few will end up in private hands and public access will be limited. All concerned have done an admirable job but will the restricted outlets and benefits prove worth it?

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