TITLE: Future Aluminium Technologies and Their Application to Aircraft Structures

TITLE: New Metallic Materials for the Structure of Aging Aircraft [les Nouveaux Materiaux metalliques pour les structures des aeronefs d'ancienne generation]

Future Aluminium Technologies and their Application to Aircraft Structures

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1. Introduction

Aluminium remains a predominant material for airframes. Carbon fibre composites and titanium alloys have made inroads especially in some military airframes such as Typhoon and Tornado. However with affordability now having equal emphasis to the classical performance requirements in aircraft design, such as speed, range, payload and stealth, aluminium could soon recover some of these applications. Aerospace manufacturers are giving significant attention to developments in the areas of new aluminium materials, low cost manufacturing and unitised structures. The latter is because the cost of producing aircraft is being driven by the cost of assembly which drives production towards fewer, cheaper-to-assemble parts, whilst maintaining close tolerance in manufacture.

2. Emerging trends in aluminium based materials

Currently, the main aluminium alloys used by the UK airframe manufacturers are the high strength Al-Zn alloys 7050, 7150 and 7010 primarily used in strength critical structures and the damage tolerant Al-Cu alloys 2024, 2014 for fatigue critical applications. There are occasional exceptions to this such as superplastic 7475 on Typhoon and high temperature 2618 on Concorde but overall these materials predominate. Thus there is immediate scope for introducing the new higher strength Al-Zn alloys such as 7055 and 7449, the new higher toughness Al-Cu alloys 2024A and 2524 and the new high stiffness, lower density Al-Li alloy 8090 into new airframe applications. These alloys should be able to deliver improved performance fairly readily with the Al-Li alloy particularly being able to offer a 10-15% weight saving providing that the cost premium can be tolerated.(Note 7055, 7449 and 2524 are single sourced which raises commercial issues also.)

The developments on aluminium based materials are progressing on a number of fronts and include strength improvements to Al-Zn and Al-Li alloys, damage tolerance improvements to Al-Cu and Al-Li alloys, high temperature aluminium alloys, high stiffness particulate aluminium matrix composites and the hybrid laminates such as GLARE ™.

2.1.Strength Improvements to Al-Zn and Al-Li alloys

The composition and thermal processing of 7XXX is being further optimised to meet requirements for upper wing skin and extruded stringers. Higher Zn additions (.>8% and similar to 7055 and 7449) have improved attainable compressive strength (~10%) at no penalty to toughness and work continues on the optimisation of these alloys. The improved heat treatment practices such as the retrogression and reageing treatments have improved the stress corrosion cracking and exfoliation resistance compared to 7150-T651.

The alternative to the use of the high strength Al-Zn alloys at very high levels of compressive strength would be the adoption of a high strength Al-Li alloy where the combination of the reduced density and extra stiffness could be taken to offset the need for a very high compressive yield strength. Two UK potential alloy options are available, the first which has stemmed from the Brite-Euram (HSALLI) programme is B13 and the second which has come from MOD research is the isotropic alloy X.

The US Al-Li alloy 2195 (Weldalite) appears to be a cost effective replacement for 2219 in weldable space structures (cryogenic tanks) because its high strength provides superior weight savings. (1) However the material is still heavy relative to normal Al-Li alloys.

2.2.Damage Tolerance Improvements to Al-Cu, Al-Mg and Al-Li alloys

Pechiney (2) have been developing a copper rich 6XXX series alloy that is aimed at replacing 2024-T351. The material offers significantly improved intergranular corrosion resistance and weldability over 2024-T351 at equivalent strength, fracture toughness and fatigue crack growth resistance.

ALCOA (1) have been developing a weldable Al-Mg-Sc alloy intended for use as thin section fuselage components, both sheet and extrusions. The claimed advantages include improved corrosion resistance and lower density when compared with current 2XXX alloys. They have also been developing a modified 2XXX with minimal recrystallisation for thin (and thick) extruded applications to replace 2024/2224. They claim higher strength, minimal machining and improved damage tolerance.

Sumitomo Light Metal Industries, Japan (3) have developed a Al-Mg-Si-Cu alloy with similar properties to 2024-T351 but with the added advantage of good formability and corrosion resistance of 6XXX series alloys. The pressure deck beam of an aircraft was extruded from this alloy. This alloy in a T6511 condition was stronger than 2024 and offered better corrosion resistance. The cost saving of the beam using this extrusion was estimated at 29%.

The UK has been developing dilute Al-Cu-Mg alloys which have demonstrated exceptional damage tolerance in an artificially aged condition and which should provide damage tolerance in a creep aged condition.

The US Al-Li alloy 2097 has good fatigue resistance and is targeted at bulkheads where it should eliminate the need for periodic replacement of 2124, which can develop fatigue cracks..(4) Application to F16 appears to be underway on a case specific basis.

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A new UK alloy ALFSOTATS (Aluminium Lithium Fuselage Sheet Optimised for Toughness and Thermal Stability) has been developed which combines dilute composition and a novel heat treatment to produce a material of superior fracture toughness than 2024-T3. (5) The material is targeted at large civil type fuselages.

2.3 The high temperature aluminium alloys

A recent Brite-Euram programme has developed an aluminium alloy for use at 150°C using conventional ingot metallurgy. The new alloy, designated 2650, derived from 2618 through the optimisation of the chemical composition presents improved mechanical properties, mainly toughness and creep, compared to 2618 alloy which up to now has been considered as the reference for elevated temperature applications.

US work on high temperature aluminium alloys for supersonic transport applications has been reported by NASA and Lockheed-Martin. Weldalite alloys RX818 and ML377 and ALCOA alloys C415 and C416 were examined. Better creep properties were exhibited compared to 2618. (6)

A current Brite-Euram programme is developing an aluminium alloy for 200°C plus temperatures using both rapidly solidified aluminium powder and mechanical alloying techniques. The alloy is still in the research phase.

2.4.Spraycast Alloys

Osprey Metals have extended the work done by Alusuisse and Alcan and are now producing a very high strength spraycast 7XXX alloys for commercial evaluation, in billets up to 100kg. (7) The alloy has a Zn content of 11.5% and is believed currently to be the highest strength commercially available 7XXX alloy.

2.5.Mechanical Alloyed Materials

The UK high stiffness particulate metal matrix composites, for example, AMC225xe, produced by mechanical alloying using an Al-Cu alloy base have progressed to small scale commercial production. The material demonstrates gains in specific stiffness approaching 50% and possesses reasonable ductilities.

The mechanically alloyed Al-Mg-Li alloy, AMC 500, which was derived from 5091 has excellent mechanical properties and corrosion resistance and does not require heat treatment. The material offers an 8% density reduction and 15% increase in elastic modulus compared to 7XXX series. The elimination of the final heat treatment is attractive in terms of manufacturing procedures, quench sensitivity, distortion and costs. There are issues around scale up but industrial interest in the material appears substantial.

2.5. The hybrid laminates such as GLARE ™

US work on the fibre reinforced aluminium laminates has continued. The target for second generation GLARE laminates appears to be a civil type fuselage crown where weight savings may be possible with improved durability and damage tolerance.(1)

3. Emerging trends in aluminium manufacturing technology

Manufacturing represents about 95 % of the cost of the airframe, and ways to reduce costs and simplify production are being vigorously pursued. Efforts to reduce the number of fasteners and part count has focused on the design of unitised structures, near-net shape forming, high-speed machining and joining technologies particularly friction stir welding. The cost effective processes such as high strain-rate superplastic forming, creep forming and casting are also receiving considerable attention.

3.1 Unitised integrally stiffened structures

Cost savings of 40 to 50 % may be possible with alternative design approaches that use integral and welded structures to replace the conventional built-up structures.

Boeing, Northrop Grumman, ALCOA, and NASA in the US (8) and British Aerospace, British Aluminium, and Wyman Gordon in the UK are involved in producing integrally stiffened aluminium panels and addressing the crack propagation issues. Two manufacturing techniques are being investigated, machining from solid and extrusion.

3.1.1 High Speed Machining from thick plate

Whilst numerically controlled machinery is a well established process, the advent of high speed machining to produce structural components from thick aluminium plates offers a number of advantages. These include reduced make-span time, consistent quality and the ability to machine thin walled components.

Historically, the balance of properties such as strength, damage tolerance, corrosion resistance and low residual stress required for aerospace applications were difficult to achieve in thick gauges where slow quench rates and low deformations dominate. However, ultra thick plate materials greater than 150 mm are currently under consideration for large components.

Pechiney have proposed an alloy designated 7040 with lower magnesium and copper levels to reduce quench sensitivity in thick sections.(9) Century Aluminium are offering 7050 plate up to 200 mm thick with a class A ultrasonic standard and mechanical properties only marginally reduced from those of 150 mm.(10) ALCOA are also developing thick 7050-T74 material.

BF Goodrich has developed the 'Grid-Lock' structural system in which a cellular structure is produced rather cleverly from machined, interlocking components.(11)

3.1.2. Extrusion

It is possible to extrude wide panels with integral stiffeners and this technology has been applied to transport aircraft in the former Soviet Union where the facilities to produce such extrusions exist.

Both Boeing and NASA are considering extruded integral stiffened panels as opposed to riveted aluminium skin and stringer construction or integral machined thick plate. Furthermore the two companies are also involved in joint ventures with The Welding Institute (TWI)) and anticipate using a friction stir welded structure in space launch vehicles in the near future.

Closer tolerances in the extrusions are being investigated to reduce costs by minimising the extra operations involved with fitting mating parts.

3.2 Joining

Technologies to join stiffeners to the sheet metal components, extruded section to extruded section and produce the large integrally stiffened structures are being actively investigated. Recent progress has resulted in an increase of confidence in the potential application of welding to primary structures.

Welding technologies that produce joints without significant heat input allow high fractions of the base metal strength to be retained. Laser welding and friction stir welding are examples of such technologies. Laser welding can save both cost and weight, while improving corrosion resistance while FSW results in higher weld ductilities than laser welds.

3.3 Superplastic Forming (SPF)

The superplastic forming of complex shapes including perhaps integral structures is appealing as it is a "single shot" process that achieves net shape forming. A main problem has been the low forming rates for the aerospace materials.

Recently high strain rate superplastic forming has been demonstrated in a number of aluminium based materials at strain rates greater than $10^{-2}s^{-1}$. This was achieved by grain refinement (<3μm) either conventionally or through processes such as mechanical alloying or equal channel angular pressing.

ALCOA, for instance, is developing a new superplastically formable (SPF) sheet which offers weight savings by parts consolidation. The new 7XXX alloy containing scandium is said to combine a high forming rate with the high strength of 7475-T6.(1)

NASA has also reported work on integrally stiffened aluminium panels made by SPF with cycle times down to 4 minutes and using a high temperature adhesive to form joints.

SKY Aluminium (Japan) have developed a method of producing integrally stiffened aluminium structures by roll bonding and superplastic forming. The sheets are clad over certain areas and hot roll bonded to form a layered sheet structure. A small amount of gas generant (used in automobile air bags) is placed into the unbonded areas between the sheets. The roll bonded clad sheets can be heated in a die and gas will be spontaneously produced to expand the structure to the desired mould shape with an internal honeycomb structure.(12)

3.4. Creep Age Forming.

The advantages of creep age forming are that conventional materials can be used and residual stresses are lower. The process can not normally be applied to lower wing skins in 2XXX alloys used in the T351 condition, i.e. stretched and naturally aged. There would be strong interest in using this process for lower wing skins as they have considerably more form than upper skins and various programmes are active in this area. The overriding factor is whether lower wing skins can be formed by this process whilst retaining sufficient damage tolerance.

3.5 Shape Castings

Castings offer the potential for significant cost and mass reduction compared to built-up fabricated structures. In particular, casting technology developments are making it possible to reduce post-casting operations such as machining and assembly. Greater shape flexibility is also possible and the reduction in fasteners due to reduced parts count reduces mass. Whilst castings currently have limited uses on airframe structured, they may find applications on severe curvature skins.

Castings for secondary structures have displaced riveted assemblies, for example on Typhoon. Enabling technologies for castings as primary structures either already exist or could be developed. In general, castings will find their application in components and assemblies of high complexities

4. The exploitation of the new technologies

The selection and exploitation of the new aluminium materials and manufacturing technologies will be a key issue in the competition between aircraft manufacturers, in terms of production costs, performance and enhanced structural integrity. Substantial cost savings in comparison with polymer composites and titanium structures are envisaged. The new technologies coupled with integration of the design and manufacturing process, improving relationships between the primes and their suppliers, the digitisation of the factories will improve the affordability of the new airframes .

The application of these new technologies into older airframes, however, is less clear cut. UK fleet sizes are small, project budgets are small and consequently the qualification and certification costs for the new technologies will tend to prevent their application to the older airframes.

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