# NEW LIGHTWEIGHT ALLOYS FOR WELDED AIRCRAFT STRUCTURE

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## Abstract

*Materials and material technologies have a large impact on the direct operating costs of civil aircraft. Materials and material technologies have an effect in excess of 70% on these costs, for example, capital costs and costs for fuel, maintenance, etc. This explains the crucial importance of the new development and refinement of aluminum materials for the aeronautics industry.*

*These considerations have prompted Airbus Germany and EADS Corporate Research Center Germany in cooperation with competent partners to develop new weldable aluminum alloys which, in addition to weldability, meet further requirements as aeronautic materials [1-5]. These efforts have supported the intensive development of Airbus's welded integral fuselage.*

## 1 Material concepts for aircraft construction

Although there have been few changes in the material distribution of steels and titanium alloys in the course of the development of the Airbus aircraft family, the use of fiber-reinforced plastics has increased at the expense of aluminum alloys. Because of their considerable weight-saving potential, the percentage of fiber-reinforced plastics in the Airbus A300 has grown in comparison to today's A340 from less than 5% to 13% of the aircraft's structural weight. Meanwhile the key development goal of research into new materials and material technologies for fuselage structures has become to achieve cost reductions while maintaining the same weight or even cutting weight. In the 1980s the Al-Li alloys 2090 (Al-Li-Cu) and 8090 (Al-Li-Cu-Mg) were developed. However, the weight-saving potential of these materials did not justify their two-to-four-times higher costs in comparison to the standard aeronautic materials 2024 and 7075. The importance of titanium alloys in future widebody aircraft such as the Airbus A3800 is likely to increase due to growing strength requirements. The potential of thermoplastic materials in terms of their growing use in future aircraft is judged to be small. By contrast, the bonded aluminum composite material Glare, consisting of aluminum sheets (0.3 to 0.5 mm) and unidirectional or multidirectional glass fibers of approximately equal thickness will very likely find its way into the next Airbus aircraft family. This material is distinguished by high strength, good fatigue strength, good damage tolerance behavior, and low density. The material's more extensive use is stymied at the moment by its high costs.

## 2 New fuselage and materials concepts

### 2.1 New metallic fuselage construction

Aircraft manufacturers have stepped up their research activities in the field of the construction of aircraft fuselage shells. The reasons for this shift in emphasis include growing demands on damage tolerance of fuselage structures, increased cost pressure in the battle for market shares among aircraft manufacturers, and the requirements of airlines for lower aircraft inspection and maintenance costs. New trends in the construction and manufacture of aircraft fuselage have therefore emerged in which welding, bonding, and extrusion are increasingly replacing the use of rivets.

The aim of ongoing research and development work on the new metallic fuselage is to achieve significant cost and weight savings in comparison to conventional aluminum-rivet construction. New integral fuselage construction methods, such as laser-beam welding of fuselage structures, are expected to cut weight and costs by more than 15%.

Laser-beam welding is predestined for joining fuselage structures thanks to low heat exposure of components, a narrow welding seam, a high process speed of 1000 cm/min in comparison to 10 cm/min for riveting, and a high degree of automation potential. Because of these advantages laser-beam welding is eminently suitable for welding skin-stringer joints. The realization of this concept presupposes the availability of weldable aluminum alloys that meet the requirements for outer skin structures The butt-joining of skin sheets can be realized by means of FSW friction stir welding. In this process the joint is achieved by kneading the edge areas of the parts being joined. In this way materials can be joined that are otherwise metallurgically incompatible for welding purposes.

## 2.2 New materials concepts

At the time work was started on the welded aircraft fuselage, the only alternative to the Al-Cu-Mg alloy 2024 was the precipitation hardenable Al-Mg-Si-Cu alloys 6013 and 6056. Although these had a lower density, their corrosion resistance was inadequate. Because of this EADS Corporate Research Center Germany undertook in close cooperation with aluminum manufacturers and research institutions to develop weldable, corrosion-resistant alloys such as Al-Mg-Sc alloy (5XXX+Sc). Some of these materials exhibit more favorable properties than 2024.

Table 1 shows the chemical compositions of the new materials. Some of the material tests were carried out at EADS CRC Germany in Ottobrunn and some at Airbus in Bremen. The comparative materials used were 1.6 mm sheets of alloy 2024 (clad) in the cold-precipitation-hardened T351condition, 6013 in the fully hardened T6 condition, and 1.4 mm sheets of 6056 alloy in the T78 temper. Alloy 1424 was available in 4.0 mm sheet in a three-stage heat-treated condition, and 1.75 mm Al-Mg-Sc sheet was available in the back-annealed condition. The Al-Mg-Li alloy has the greatest weight-reducing potential in comparison to alloy 2024 thanks to its very low density and high modulus of elasticity (Table 2).

The yield strength of the new materials is above the value of the conventional alloy 2024 (Fig. 1). Only alloys 1424 and 5XXX+Sc achieved the tensile strength level of 2024 (Fig. 2). None of the alloys achieved the values of the comparative alloy, whereby 1424 and 5XXX+Sc exhibited greater elongation anisotropy due to the marked recrystallization-inhibiting effect of scandium (Fig. 3). The thermal exposure of 85°C/1000 h caused no appreciable change in the strength values. The elongation-after-fracture values for 6056 increased, while those of 1424 and 5XXX+Sc fell slightly.

The results regarding the mechanical properties and corrosion behavior of alloys 1424 and 5XXX+Sc are so far very promising. No less positive have been the results of the tests of the materials' welding properties (TIG, MIG, $CO_2$ laser). The filler metal used for the AlMgSc alloys was an alloy similar to the material itself (015XX with scandium). Alloy 1424 was also welded using the TIG and $CO_2$ laser techniques with a filler metal resembling the material itself (01571 with scandium). Fig. 4 compares the welding factors (strength ratio of joint to base material). The highest welding factor values of approximately 0.71 were achieved with $CO_2$ laser-beam welding of Al-Mg-Sc alloys. Heat treatment of the welded

| Alloy | | Mg | Mn | Sc | Li | Zr | Si | Cu | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Al-Cu-Mg | 2024 | 1.2–1.8 | 0.3–0.9 | – | – | 0.2* | <0.5 | 3.8–4.9 | <0.25 |
| Al-Mg-Si-Cu | 6013 | 0.8–1.2 | 0.2–0.8 | – | – | – | 0.6–1.0 | 0.6–1.1 | – |
| | 6056 | 0.6–1.2 | 0.4–1.0 | – | – | 0.2* | 0.7–1.3 | 0.5–1.1 | 0.1–0.7 |
| Al-Mg-Sc | 5XXX+Sc | 3.0–6.0 | Mn | Sc | – | Zr | 0.11 | 0.029 | – |
| Al-Mg-Li | 1424 | 5.35 | – | 0.08 | 1.63 | 0.09 | <0.05 | – | 0.65 |

*Ti + Zr

Table 1: Chemical composition of aluminum alloys for fuselages.

| Alloy | | Density ρ [g/cm$^3$] | Young’s modulus [MPa] | Δ ρ [%] | Δ Young’s modulus [%] |
|---|---|---|---|---|---|
| Al-Cu-Mg | 2024 | 2.78 | 69000 | – | – |
| Al-M-gSi-Cu | 6013/6065 | 2.71 | 70000 | -2.5 | +1.5 |
| Al-Mg-Sc | 5XXX+Sc | 2.65 | 73000 | -4.7 | +5.8 |
| Al-Mg-Li | 1424 | 2.52 | 77000 | -9.4 | +11.6 |

Table 2: Physical properties of the new alloy in comparison to 2024.

seams increased the welding factor to 0.9 and to 0.74 for Al-Mg-Li alloys, whereby the joint strength of the Al-Mg-Sc alloy (384 MPa) was on the same order as that of 1424 (360 MPa).

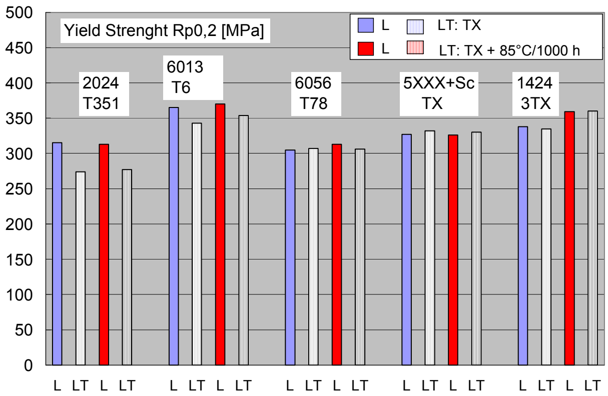

Fig. 1: Yield strength in MPa of the new alloys in the heat-treated condition and after exposure to 85°C for 1000 h; specimen positions L and LT.

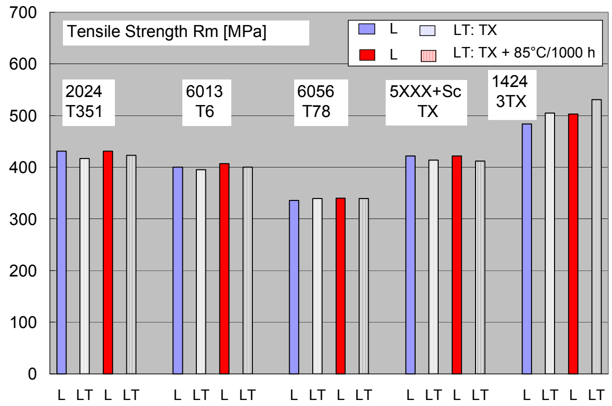

Fig. 2: Tensile strength in MPa of the new alloys in the heat-treated condition and after exposure to 85°C for 1000 h; specimen positions L and LT.

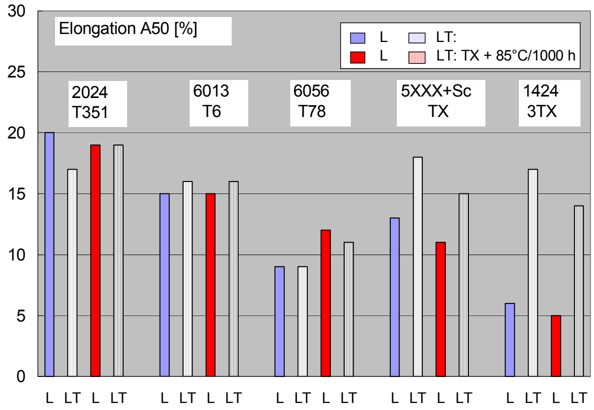

Fig. 3: Elongation $A_{50}$ in % of the new alloys in the heat-treated condition and after exposure to 85°C for 1000 h; specimen positions L and LT.

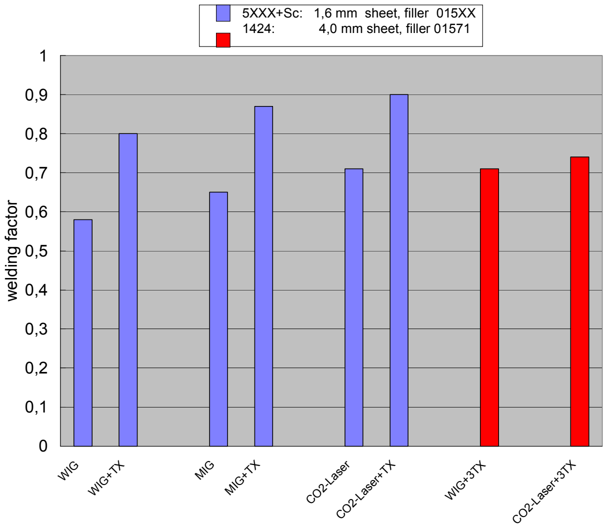

Fig. 4: Welding factors (strength ratio of the joint to the base material) of the new alloys Al-Mg-Sc and Al-Mg-Li after TIG (WIG), MIG and $CO_2$ laser-beam welding with and without heat treatment; welded seam prepared.

## 3 Summary

The tests of the new aluminum alloys discussed here indicate that they could potentially be used in civil aircraft construction for manufacturing integral fuselage structures by laser-beam welding to achieve weight and cost savings. Which of the new alloys and in which material combination (e.g. skin-stringer joints) will be used in dynamically stressed fuselage areas (where damage tolerance is essential) and in static areas subjected to tensile and compressive forces or corrosive influences can only be decided on the basis of barrel tests, in which real flight loads are simulated on aircraft fuselage shells.

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