HIGH PERFORMANCE MATERIAL FOR AEROSPACE APPLICATIONS

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ABSTRACT.
Driven by the increasing requirements from aircraft producers Hoogovens Aluminium Rolled Products GmbH, together with Hoogovens Research & Development, has enhanced the property combinations of their aircraft materials. For these types of material optimised processing routes as well as new alloy chemistries have been investigated. Whilst retaining the strength levels required by the aerospace industry, new processing routes offer major improvements in ductility, toughness, fatigue performance and in reduction of residual stress in large dimension plate and sheet products. A further goal of investigating new alloy chemistries is the trend towards new bonding techniques such as welding and brazing for aircraft structures. These new joining techniques require different property combinations compared to the "conventional" aerospace alloys. In parallel to these improved processing routes and new alloy developments, new ultrasonic inspection techniques have been developed which are able to predict fatigue performance and residual stress in thick plate products.

Keywords: *Aerospace, Mechanical Properties, Residual Stress, Plate*

1.INTRODUCTION

The aircraft industry is constantly striving for improved materials which enable higher performance at reduced cost. One of the key driving forces is the reduction in manufacturing cost. In this context there is a trend to reduce the number of joints by the manufacture of monolithic structures and the use of larger plate and sheet sizes. In addition for future aircraft the airframe manufactures are looking at the application of new technologies. In this paper these trends are illustrated with a number of examples.

2.THICK PLATE PRODUCT

The development of high speed milling machines has led to the conclusion that large machined structures can significantly reduce cost by reducing the number of components and joints. These machined structures can be up to 30 m long and 280 mm thick. Up to 95% of the material is removed and the aspect ratio after machining can be as high as 35:1. In order to meet the manufacture's needs several key properties of the plate had to be improved (ductility, toughness and fatigue) and the material has to have minimum residual stress so that distortion free machining can be performed in a single operation (1). Currently machined structures are made from forged material which need to be heat treated and stress relieved partway through machining to minimise distortion. This is both a time consuming and an expensive operation due to the need to manufacture special dies to carry out the stress relieving process.

In order to meet the customer's target a multi-discipline Integrated Product Development (IPD) team approach was initiated. This team, involving internal and external experts, carried out extensive laboratory and plant testing prior to commercialisation of the approach. The work concentrated on alloy 7050, which is the workhorse of the plate market, but the results are applicable to other high strength plate alloys. The main details of the basic laboratory work (2,3) and the production aspects (4) have been published elsewhere, thus only the key salient features will be described below.

2.1 Improved fatigue

Conventional 7050 plate products have fatigue performance well above the specification requirements (A minimum life of 120 kcycles at a stress level of 241 MPa L-T orientation) up to about 125 mm in thickness (see curve 1 in figure 1). Above this the fatigue life drops rapidly which limits the effective gauge to 150 mm. It has been established that this is due to micro-porosity, formed during the casting process, not being fully closed during rolling and thus acting as an initiation site for a fatigue crack (see figure 2). In order to minimise the number of micro-pores it is necessary to modify the casting method to ensure that there is minimum porosity due to shrinkage at grain boundaries, which can not be filled by molten aluminium, and to design the rolling process (temperature, pass schedule) so that any residual fine pores are closed during rolling. Special attention to the above details enables a significant improvement in fatigue performance for plate up to about 220 mm (curve 2 in fig1). For very thick plates (i.e. up to 280 mm) there is more limited scope to close shrinkage porosity during rolling, since it is difficult to ensure sufficient strain in the plate centre. Therefore, it has been necessary to further modify the processing route to optimise the fatigue performance. The results are shown in curve 3 in Figure 1.

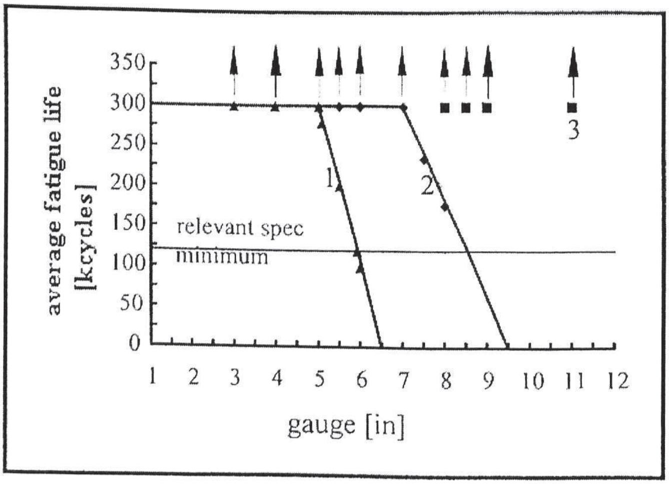

Figure 1: Average fatigue life per lot as a function of 7050 T7451 plate thickness for three different processing routes

Figure 2. Micrograph of pore as initiation site for fatigue crack.

It is axiomatic that these developments in thick plate product for critical applications necessitate the development of improved NDT techniques for material characterisation to ensure that the above property criteria are met. Particular emphasis is placed on the development of techniques to determine such properties as fatigue performance and residual stress. The reader is referred to reference 5 for detailed information on the state of the art.

2.2 Improved ductility and toughness

Table 1 shows the plain strain fracture toughness for the L-T and ST-L testing direction and the ST ductility for 100,150 and 220 mm thick 7050-T7451 plates. The table shows a comparison between the old and new (improved) industry requirement and the values achieved with conventional and improved processing. It is obvious that the improved processing has resulted in improved damage tolerance for all plate gauges. It should be noted that there is no data for 220 mm plate conventionally processed since this product was not used in such heavy gauges before the development of the improved processing.

Table 1. Comparison of old and new specifications and properties of thick 7050-T7451 plates

PLATE	**K_{1c} T-L ksi$\sqrt{in}$**		**K_{1c} S-L ksi$\sqrt{in}$**		**ST Elongation %**	
THICKNESS mm	**OLD**	**NEW**	**OLD**	**NEW**	**OLD**	**NEW**
100 mm spec	23.0	26.0	21.0	23.0	2.0	3.0
100 mm measured	27.0	28.5	24.0	27.5	4.7	5.6
150mm spec	23.0	24.0	21.0	23.0	2.0	3.0
150mm measured	24.5	28.0	24.5	30.0	3.8	5.4
220 mm spec	20.0	22.0	20.0	22.0	2.0	3.0
220 mm measured	N.A.	27.5	N.A.	27.0	N.A.	5.7

N.A. Indicates that no data available

2.3 Minimum residual stress

Figure 3 shows the so-called distortion profile obtained during machining of a full thickness 280 mm thick 7050 plate. The profile was determined by incrementally milling 12.5 mm down to the plate mid-thickness. The maximum allowable distortion according to industry requirements is ±0.25 mm. The data shows a maximum distortion of only ±0.05 mm after machining to the mid-thickness line. This was typical for all tests carried out on other relevant plate thickness.

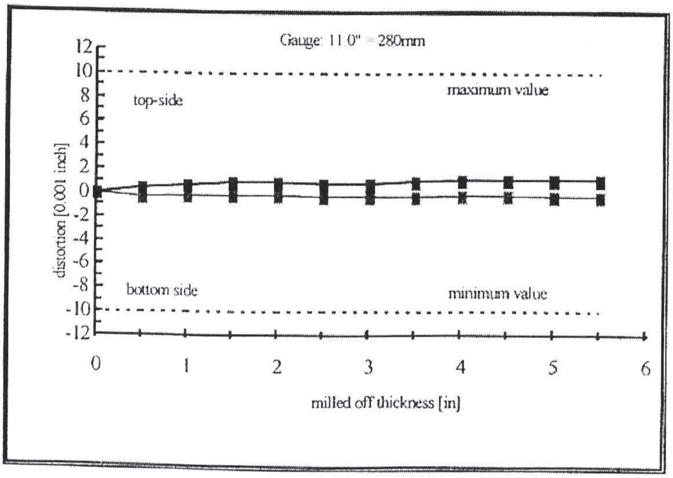

Figure 3: Distortion profile of an 280 mm thick 7050 plate.

3. AIRCRAFT SHEET

In addition to the requirement for thicker plate products airframe manufactures are demanding larger sheet in 2024 base alloys for use as fuselage skin materials. The large sheets offer substantial saving in manufacturing costs by reducing the number of joints in the structure. Hoogovens Aluminium Rolled Products, Koblenz has developed the production route for sheets with dimension of up to 3.2 m width and up to 12.7 m in length (6). In addition improved damage tolerance can be achieved within the 2024 alloy chemistry window by careful control of chemistry and processing.

3.1 Alloy chemistry

In order to examine some of the effects of alloy chemistry of 2024 type alloys on strength and toughness a series of small 10kg ingots were produced and processed to 2mm sheet and converted to the T3 temper. Tensile properties were determined in the L and LT test directions and Kahn tear tests used to estimate the material's fracture toughness in the L-T and T-L direction. This is an established test for ranking damage tolerance and can be correlated with plain stress fracture toughness and has a statistical error of 5-10%. The tests gives two measures of toughness the ultimate propagation energy (UPE) and the ratio of the tear strength (TS) with the material's

0.2%PS. Details of the test and its application for estimating plain stress toughness are given in references 7 and 8. Table 2 shows the results of this investigation.

Table 2. The alloy chemistry and mechanical properties of 2mm T3 samples. In the data column the data for tests carried out in the longitudinal direction are given first and those in the transverse direction given second.

Alloy	**Alloy Chemistry wt%**			**0.2%PS**	**UPE**	**Ratio**
	Cu	**Mg**	**Mn**	**MPa**	**MPa/mm**	**TS/PS**
A	4.46	1.39	0.68	349/309	446/487	1.59/1.72
B	4.07	1.38	0.70	344/305	546/543	1.64/1.79
C	3.59	1.39	0.70	323/279	570/653	1.72/1.92
D*	4.12	1.43	0.69	348/307	534/574	1.68/1.81
E*	4.12	1.44	0.32	321/293	669/593	1.75/1.91
F	4.12	1.44	0.31	328/296	691/672	1.77/1.93
G*	3.49	1.59	0.32	313/288	813/782	1.81/1.95
H	4.06	1.50	0.63	332/294	624/540	1.71/1.83

* also contains 0.12 Zr

The results show that tests in the transverse orientation give lower strength and in general, a better toughness indication. For comparison typical values for 2024-T3 quoted in ref 7 are a UPE of 500 MPa/mm and a toughness ratio of 1.55. Reducing the alloys copper content (alloys A,B and C) results in lower strength and higher toughness indications. Lower manganese (alloy F) gives a higher toughness indication at similar values of 0.2%PS. Increase magnesium (alloy H) also appears to improve toughness. There is no significant benefit of zirconium addition on either strength or toughness.

3.2 Improved damage tolerance

The results of the alloy chemistry investigations have been translated into commercial practice. Table 3 shows the typical property requirements of this improved 2024-T3 sheet compared with the industry requirements for "standard" 2024-T3 sheet.

Table 3. Property requirement for 2024-T3 sheet products

Material	LT 0.2%PS MPa	Kc T-L MPa√m	da/dn at Δk=30 MPa√m R=.1
Standard 2024-T3	270	85	4x10^{-3} mm/cycle
Improved Versions	270	110	1.2x10^{-4} mm/cycle

4. NEW STRUCTURAL CONCEPTS

In addition to the above development in "conventional" alloys for current aircraft construction, airframe manufactures are looking at the possibility of using new joining technologies for future airframes. These new techniques often involve some form of welding technology pioneered in the former Soviet Union in their aluminium lithium development. In order to maximise the potential cost saving of using these techniques new alloys and technologies are under development. There is insufficient space to go into detail on all the new developments in this paper. The main areas under investigation by Hoogovens and the airframe companies are indicated below:-

Weldable aluminium lithium alloys. The Russian alloys 1420 and 1421 have been investigated as candidates for welded fuselage structures and improved alloy variants are under development (9,10). These give excellent weldability with welded strength of around 2024-T3 design valves.

6000 series alloys. Alloy 6013 was developed to give a 3% weight saving compared to Alclad 2024-T3 with a reduction in material price and improved forming characteristics (11). However the alloy showed a tendency to have lower corrosion performance under certain test conditions. Modified alloy chemistries are under development which give improved corrosion performance (9).

Al-Mg-Sc alloys (12,13). These alloys show much higher strengths compared to conventional Al-Mg alloys. This is due to the presence of Sc which inhibits recrystallization. The alloys have strength similar to 2024-T3 and are weldable.

Friction stir welding. This technology was developed at TWI and has shown to be applicable to welding large structures in marine applications (14). It is now under development for welding of 2000 and 7000 alloys for possible application in airframe structures. The main metallurgical advantage of the technique is that the welding is carried out in the solid state.(15,16)

5. CONCLUSIONS

1. The new high strength thick plate products developed at Hoogovens Aluminium Rolled Products, Koblenz enable the airframe manufactures requirement of improved fatigue, higher damage tolerance and virtually distortion free machining to be met in plate products up to 280 mm in thickness.
2. Developments in 2000 series damage tolerant sheet enable extreme dimension sheet (3.2 m by 12.7 m) to be produced within the 2024 chemistry window with high toughness and fatigue crack growth performance.
3. Co-operation (of material suppliers) with airframe manufactures enables the development of "novel" alloy combinations so that new joining technologies can be taken advantage of whilst improving overall product performance at lower overall cost.

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