Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

DEVELOPMENT OF HIGH STRENGTH ALUMINIUM ALLOYS AT BALCO

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ABSTRACT

Aluminium is one metal that makes soft kitchen foil forms the vital high strength parts of aerospace vehicles. To cater to the needs of the aerospace sector and for enhancing market share in the premium products category, BALCO jointly with Vikram Sarabhai Space Centre, ISRO, has established facililities for production of various high strength aluminium alloys for Aerospace and Defence Sectors.Bharat Aluminium Company Ltd. (BALCO) has been closely associated with the growth of Indian aluminium industry. It has played a pivotal role in making aluminium one of the leading metals of the 21st century with myriad uses ranging from house hold and industrial requirements to Defence and Aerospace applications. BALCO has contributed significantly as a primary producer by providing sustenance to vital industries and has proved its mettle by developing and supplying Aerospace grade aluminium alloys to Vikram Sarabhai Space Centre for their Space Launch Vehicles Programmes.

INTRODUCTION

Discovered as an element just about 200 years ago and manufactured commercially just half that long, aluminium today ranks behind only iron and steel among metals serving the mankind. The reason for this is its incredible versatility. The light, shiny metal that had began its working life as a precious metal, which only kings and emperors could afford, has emerged as a metal of multifarious applications in the industrial society. The same metal that makes soft kitchen foil forms the vital high strength parts of aerospace vehicles. To cater to the needs of the aerospace sector and for enhancing market share in the premium products category, BALCO jointly with Vikram Sarabhai Space Centre, ISRO, has established facililities for production of various high strength aluminium alloys for Aerospace and Defence Sectors.

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AEROSPACE ALLOYS:

The selection of material for aerospace applications is based on the design constraints. These are defined by the mechanical, chemical and thermal property requirements of each component. Typical design constraints include weight, stiffness, strength, fatigue performance (high/low cycle), corrosion resistance and cost. The broad aim for aircraft design is to maximize payload in relation to cost. By increasing specific stiffness and strength, the weight of a given component can be decreased and fuel consumption and running costs are reduced. For example when a fully loaded aircraft takes off, 20% of the weight is payload, 40% is aircraft structural weight and 40% is fuel. Therefore, a saving in aircraft weight can increase the possible payload or decrease the power required for a given payload. Aluminium alloys have a low density (2.7g/cm3) and have excellent strength to weight ratios. They have high thermal and electrical conductivity and have excellent resistance to oxidation and corrosion. All these factors have made aluminum the major material for airframe construction.

The most commonly used aluminium alloys for airframe construction are the age hardening alloys in the 2XXX, 7XXX

series and Al-Li alloys, as shown in Figure 15. Examples of the tempers given to the airframe alloys are shown in Figure 16.

Aerospace alloys (2xxx):

- The 2XXX series aluminum alloys are alloyed with copper from 1.9 to 6.8% and often contain additions of manganese, magnesium and zinc.
- These alloys have lower crack growth rates and thus have better fatigue performance, than 7XXX series alloys.
- These are used on the lower wings and fuselage (see Figure). The alloys used are 2224, 2324 and 2524.
- These alloys are often clad with pure aluminum for increased corrosion resistance.

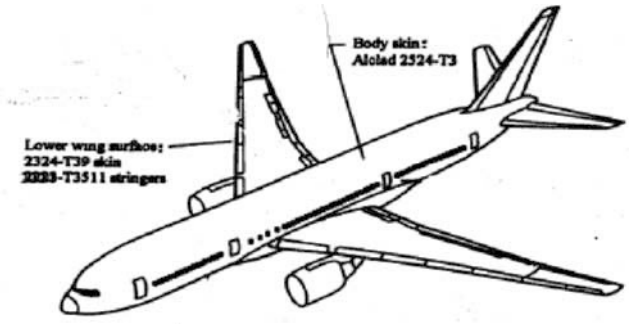

Fig.1: ***2XXX series alloys in the airframe***

Aerospace alloys (7xxx):

- The Al-Zn-Mg system offers the greatest potential for age hardening (out of the aluminum alloys) though copper is often added to improve stress corrosion cracking (SCC) resistance (with the drawback of reducing weld ability).
- Most common alloys being 7075, 7010, 7055 and 7150. All these alloys are used in the overaged T7 temper as this temper provides the best resistance to exfoliation corrosion and SCC.

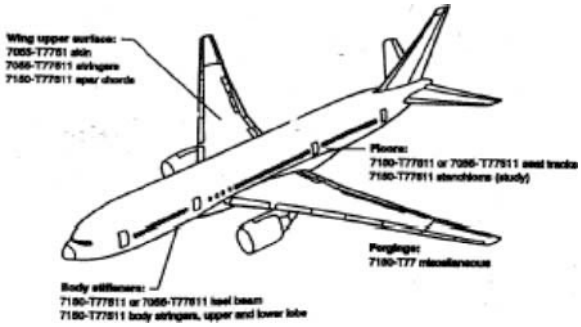

Fig.2: ***7XXX series alloys in airframe construction***

Aerospace alloys (Al+Li):

- These alloys have been developed especially for the aerospace industry with the focus on the low density of lithium (0.534 g/cm3).
- These alloys offer the attractive benefits of being 10% lighter, 10% stronger and 10% stiffer than conventional aluminum alloys,

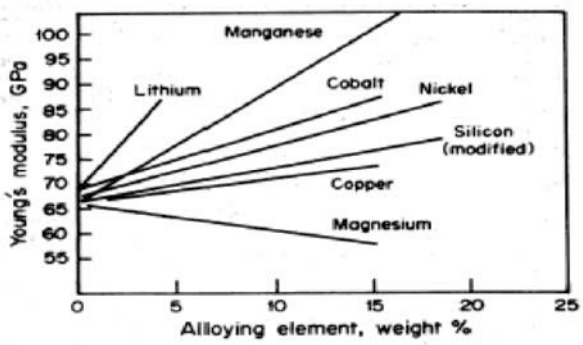

Fig.3: ***Effect of lithium on modulus of Al-alloys***

- Al-Li alloy is a candidate material for the cryogenic tank of booster systems.
- These alloys are used in cryogenic applications for example, liquid oxygen and hydrogen fuel tanks for aerospace vehicles.

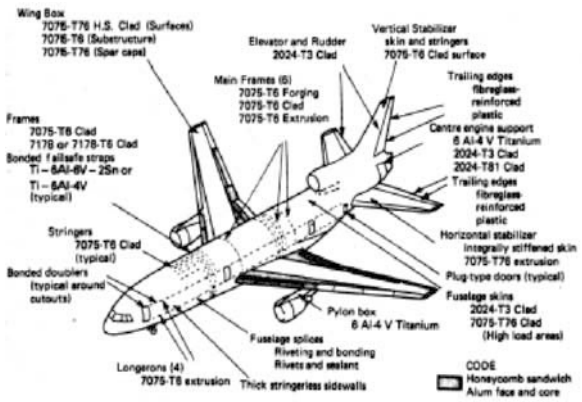

Fig.4: Critical applications with respect to design consideration.

DEVELOPMENT OF AEROSPACE ALLOYS AT BALCO:

For a long time Vikram Sarabhai Space Centre of Indian Space research Organization (ISRO) had been importing substantial quantity of aluminium plates and sheets for their Geo Stationary Launch Vehicles. As ISRO was keen to develop the aluminium

plates and sheets required for their Launch Vehicle Programmes indigenously they had contacted all the major Indian primary producers. Ultimately Balco had set up the facilities required for development of these high strength alloys, jointly with VSSC, to save the huge amount of foreign exchange going out of the exchequer of our country.

FACILITIES AVAILABLE AT BALCO FOR MANUFACTURING OF AEROSPACE GRADE ALLOYS BEFORE TAKING UP OF VSSC PROJECT:

The facilities BALCO had before initiating the joint venture of source indigenization for the Launch Vehicle Programmes of VSSC are given below:

1. **Casting Units -** Melting furnace with precision temperature controls
- On-line SNIF degassing
- Ceramic foam filter
- 15-degree tilted super caster (18000MT/A)

2. **Hot Rolling Mill** - The only 4 high Hot Rolling Mill in India (75000MT/A)
- The Mill can Roll slabs up to 1560mm wide.
- Contains Edger to minimize edge cracking

Fig.5: Hot Rolling Mill

3. **Old Cold Rolling mill** – Sturdy 4 high Mill from Russia (30,000MT/A)
- Hydraulic Automatic Gauge Control
- Configuration helps to minimize shape variation

4. **New Cold Rolling mill** - Hydraulic Automatic Gauge Control
- Shape and Flatness Control
- Capacity of 36,000 MT/A.

5. **Hard Sheet Treatment Line -** Semi Continuous Solutionizing Drop Bottom Furnace.
- 250 T Sheet Stretcher with online end shear
- Automated Sheet Handling System.

Quality Assurance Laboratory and Fabrication Pilot Plant for development of sophisticated alloys for Defense and other strategic sectors:

Balco has a well equipped Quality Assurance Laboratory and Fabrication Pilot Plant, set up with the funding of Department of Science & Technology, Government of India, for development of high strength alloys for Defence, Aerospace and other critical applications. The main facilities available are given below:

- XRF & XRD
- Pot flux analyzer.
- Optical Emission Spectrometer
- Atomic Absorption spectrometer
- Scanning Electron Miscroscope
- Metallurgical microscope.
- Erichsen sheet metal tester.
- Instron 5569
- Ultrasonic Testing Facility
- Apart from the above the R&D Centre also has a Fabrication Pilot Plant consisting of melting furnace, miniature rolling mill, wire drawing equipment, forging press and heat treatment furnaces for developing special alloys.

FACILITIES WHICH WERE AVAILABLE AFTER THE 1ST PHASE OF VSSC PROJECT:

1. **Solution treatment Furnace:**
   - Drop bottom type
   - Sheets / plates of size 100mmX 1600mm X 9000mm

Fig.6: Solution treatment furnace

2. Skin Pass Rolling Mill and roller leveller:

- 2 Hi mill – 1000 T rolling force
- Integrated vacuum handling system for loading & unloading of sheets/plate

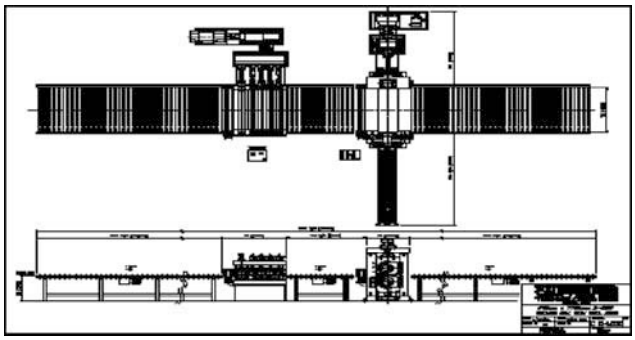

Fig.7: Line Sketch of the Plate Rolling Mill

3. Plate Stretcher:

– Hydraulic & fully automated

– For straightening & stress relieving of sheets/plates.

4. Ageing Furnace:

- Batch capacity 5T.
- Maximum temperature is 300° C

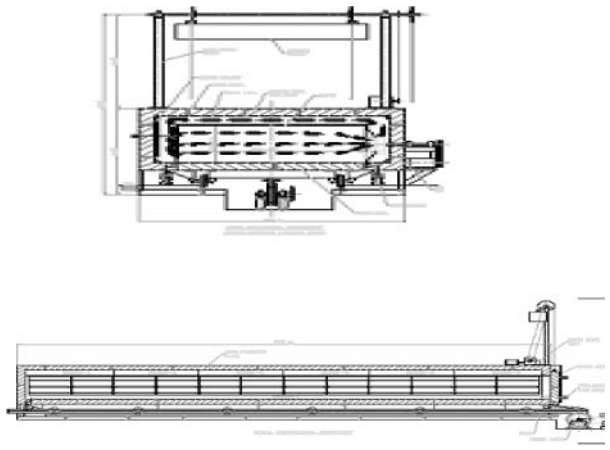

Fig.8: Line Sketch of the Ageing Furnace

5. Ultrasonic Testing Machine:

– Fully automated immersion testing

– 5 channel state-of-the-art technology with thickness mapping.

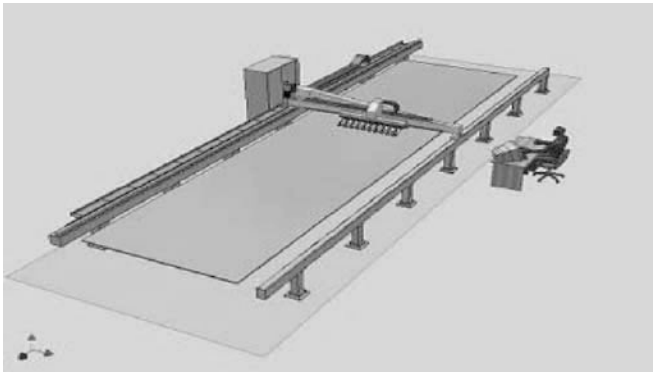

Fig.9: Line sketch of the Ultrasonic Testing Machine

5. Polishing Machine:

– Double side polishing & PVC coating

– Integrated vacuum handling system

– Dimensions

– Thickness upto 20mm

– Width upto 1600 mm

– Length upto 10,000 mm

– 6 Stage Polishing Machine.

– Capability to remove upto 5 Microns.

– Mirror finish / Matt finish as desired

– Feed – 1 Meter/ minute

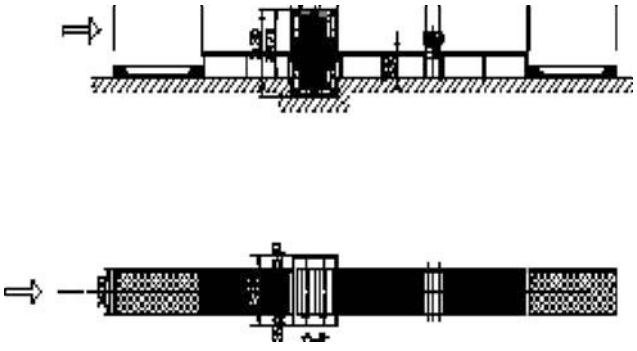

Fig.10: Line sketch of the Polishing Machine

7. Sawing Machine:

– Material: Aluminium Sheet/Plate Bundle, Length:10000 mm (Maximum), 500 mm (Minimum); Width: 1650 mm (Maximum), 750 mm (Minimum); Thickness: 100 mm (Maximum), 1 mm (Minimum)

– Accuracies Achievable: Length accuracy: +/-2 mm; Width accuracy : +/-2 mm; Diagonal accuracy: +/-5 mm

8. Material Handling System:

– Loading and Unloading of Sheets/ Plates by suction lifters into the Fixture

– Transfer of sheets from the Rolling Mill into the Stretcher by suction lifters

– Loading and Unloading system for the Ultrasonic equipment by suction lifters

– Loading and Unloading system for the Polishing Line by suction lifters

9. Cut To Length Machine:

- Maximum coil capacity of the machine is 5 Tons.
- Length accuracy of +/-5mm.
- The machine can handle sheets of length 9000 mm (max), width 1600mm (max), and thickness of 0.8-8mm.

FACILITIES WHICH WERE AVAILABLE AFTER THE 2ND PHASE OF VSSC PROJECT:

As a backward integration measure, establishment of casting facilities for producing aerospace quality slabs and billets was jointly taken up with VSSC. This made BALCO an independent source of quality aerospace materials. Thus Balco was able to cater to the needs of not only aerospace but was also in a position to supply high strength alloys, having stringent quality requirements, for various critical applications, such as Defence (Army, Navy and Air Force).

The facilities which have been set up in the 2nd phase of VSSC Project are as follows:

1. **Melting cum Refining furnace:**
   - 25 MT Capacity
   - Oil fired with regenerative burners
   - High quality non-wettable ceramic materials
2. **IRMA:**
   -In-furnace melt treatment system
   -Common for two or three furnaces
   -Mounted on top of furnace with two rotors
   -Argon & Chlorine lancing
   -Flux injection

3. ALPUR Degassing System:

-Twin Rotor

-Heating system

-Argon system with a small amount of chlorine.

-Output hydrogen level of 0.1 cc/ 100 gm of molten metal

-Alkali metal content of 2 ppm or less

-Inclusion removal to ensure choking free CFF operation

4. In-line Ceramic Foam Filter Unit:

-Twin filters

-Selective adsorption material between the two filters for removal of alkali salts.

5. Metal transfer system:

-Non wettable refractory material

-Pre heating covers to maintain temperature

6. Cooling water system:

-Maintain pH value 6.5 TO 8.5,

-TDS level below 100 PPM

-Temperature -20 to 32 deg. With +/- 3Deg. C

-Water flow rate controller & indicator

7. DC Casting Machine:

-Mold table frames

-One for billet & one for slabs

-Wiper system for cracking control for each mould table

-AA 2014, 2219, 6061, 7175, 7075 and other high strength alloys

8. Billet tooling:

-Diameter 400 mm*8/500 mm* 6/600 mm*4/ 820 mm * 2

-Smooth billet surface

-Hot top

-Level pouring to ensure turbulent free metal transfer

-Metal distribution system shall have individual ports for each mould

9. Slab tooling:

-390 * 1320 mm & 390 * 1550 mm

-Lubrication system to ensure minimum liquidation band

10. Casting machine automation package:

-Process to be integrated through Man machine interface (MMI)

-Automatic control of casting speed, water flow rate, rod feeder, degassing etc.

11 Slab sawing:

-End cutting

-End sawing and parting

-400 mm thick

-6000 / 5400 mm length

12. Billet sawing:

-Max 820 mm dia.

-Max 6000 mm length.

-Parting and end cutting

QUALITY OF THE CAST SLABS AND BILLETS:

-Ultrasonic Class A as per AMS 26300 B

-Inclusions (PoDFA Index): - < 0.05 mm^2/kg

-Hydrogen level – Below 0.1 cc /100 gm of Al

-Controlled fine Grain size

-Controlled Cell size

-Alkali metal - < 2 ppm

PRODUCTS BEING SUPPLIED TO VSSC:

The following products are regularly being supplied to VSSC for their Launch Vehicle Programmes:

1. Alclad AA 2014 T4/T6 temper sheets.
2. AA 2014 -T6 temper sheets.
3. AA 2219 - T81 & T87 temper sheets.
4. AA 2014 - T651 temper plates.
5. AA 2219 - T87 temper plates.
6. AA6061 T6 temper sheets.

PROBLEMS IN DEVELOPMENT OF HIGH STRENGTH LEVELS IN AEROSPACE GRADE AA 2014 PLATES AND SHEETS:

For achieving the high strength levels the rolled plates and sheets of AA 2014 were solution treated and artificially aged. Special care had to be taken while solution treatment was carried out to prevent grain boundary melting. Before solution treatment was done in commercial scale, solution treatment at various temperatures was carried out in laboratory scale to achieve the desired microstructure and mechanical properties. The temperature of solution treatment had to be optimized so that it was sufficiently high to minimize undissolved $CuAl_2$ (Fig.11) in the structure and not very high to prevent eutectic melting.

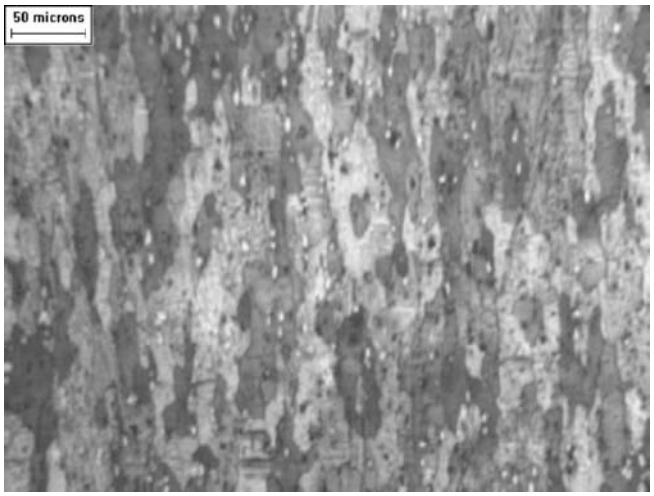

Fig.11: Photomicrograph of AA 2014 showing lot of undissolved $CuAl_2$ particles indicating inadequate solution treatment.

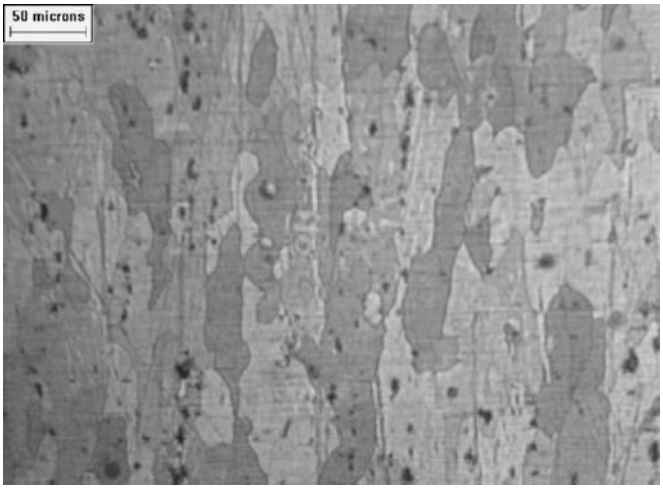

Fig.12: Photomicrograph of AA 2014 showing very few undissolved $CuAl_2$ particles indicating proper solution treatment.

After each processing step i.e. hot rolling, cold rolling, solution treatment and ageing microstructural examination was carried out to rule out occurrence of high temperature oxidation, grain boundary melting and grain coarsening. Extensive microstructural examination was done specially after solution treatment to confirm proper dissolution of $CuAl_2$. A number of samples were prepared from the various heat treated batches and testing of mechanical properties was carried out for establishing the heat treatment cycle to be followed for meeting the specified stringent requirements.

CONCLUSION:

Manufacturing of aerospace quality plates and sheets of aluminium alloys requires very stringent quality control measures. Bharat Aluminium Company has contributed significantly in the endeavor of VSSC to indigenise the sourcing of the aluminium plates and sheets required for their Geo stationary launch Vehicle (GSLV) Programmes. Close monitoring right from the casting stage to the finishing line has ensured production of superior quality, cost efficient plates and sheets for aerospace applications.

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