INDIRECT TUBE EXTRUSION OF DISPERSION STRENGTHENED ALUMINIUM

Klaus B. Mueller*, Einar Hellum**

*Extrusion Research and Development Center, Technical University Berlin, Gustav-Meyer-Allee 25,
D-13355 Berlin, Germany
**Raufoss Technology AS, Box 77, N-2831 Raufoss, Norway

ABSTRACT

This paper deals with the manufacturing of tubes from dispersion strengthened aluminium powders. The mechanical alloying of elemental aluminium was performed in a high energy horizontal ball mill in liquid nitrogen. The achieved dispersion strengthened aluminium was formed to round billets by cold isostatic pressing. The precompacted billets were degassed and later extruded by indirect extrusion with moving mandrel, keeping the inner diameter of the tubes constant at 1.18 inches and varying the wall thickness. After extrusion the tubes were reduced to required dimension with a good deal of cold drawing. Investigations were carried out in the fields of:

- influence of extrusion ratio, billet temperature and ram speed on the axial extrusion forces
- determination of the mechanical properties after extrusion
- optical micrographs
- corrosion testing

All extrusion trials were carried out on the 8MN direct/indirect extrusion press at the Extrusion Research and Development Center of the Technical University Berlin, corrosion tests were carried out at Raufoss Labs.

Keywords:
- *dispersion strengthened aluminium*
- *indirect extrusion*
- *cold drawing*
- *mechanical properties*
- *corrosion*

1. INTRODUCTION

Raufoss Technology AS, Norway, has been working with the technology of mechanical alloying (MA) since 1988. A pilot plan for mechanical alloying of aluminium was put up in order to start development of these materials.

The development of new advanced aluminium alloys has resulted in extended use of aluminium at temperatures up to 450°C. A new class of materials is the dispersion strengthened materials made by mechanical alloying.

The **D**ispersion **S**trengthened **Al**uminium, **DS-Al**, which is the most developed MA material today, consists of pure aluminium and AlN [1]. This material is produced by cryogenic milling, which is a very efficient milling technique and which enables a uniform distribution of dispersoids and a fine grained microstructure.

Mechanical alloying is carried out in a high energy ball mill where elemental aluminium powder is milled in liquid nitrogen (cryomilling). The liquid nitrogen is continuously added to the milling process. This keeps the powder and the milling media , which is steel balls, in a liquid nitrogen bath at a temperature of -195°C. The mechanically alloyed DS-Al powder is dispersion strengthened with aluminium nitrides (AlN). Compaction of the DS-Al powder is performed by cold isostatic pressing (CIP) to 80% density. Degassing of the cold compacted billet under vacuum at high temperature reduces gasses in the material to a minimum. Consolidation to 100% density is achieved by extrusion. Product forming follows the same process route as for conventional Al which includes forging, rolling, joining and machining.

DS-Al derive their strength from the interaction between insoluble particles and dislocations and are based on the formation of small nanoscale AlN particles formed during the cryomilling process. These particles have significantly better thermal stability than precipitates in conventional alloys. The typical size of the dispersoids is 10-15 nm and the grain size is less than 1μm in these materials. The most efficient size hindering dislocation motion is in the range of 10-30 nm. The dispersoids are located both on the grain boundaries and inside the grains. After extrusion or hot rolling the grains are not significantly different from that of the hot pressed material, suggesting that the dispersoids are very efficient in pinning the grain boundaries. The uniform distribution of the AlN coupled with a smaller grain size result in high tensile strength of 100-120 MPa at 450°C [2], the room temperature tensile strength is 350 MPa. As a comparison, the conventional ingot metallurgy alloy AA2219 exhibits room temperature tensile strength up to 475 MPa in temper T86, while at 370°C the strength is reduced to 30 MPa.

Physical properties on basis of the DS-Al-550 are:

Density mg/m^3	Melting point °C	Specific heat J/KgK	Thermal conductivity W/mK	Thermal expansion μm/mK	Modulus of elastic shear GPa
2.70	660	890	230	23.8	26

Additional properties of DS-Al Materials are as under:

- high corrosion resistance
- thermal stability
- excellent creep properties
- good fatigue strength
- light weight
- some specific properties are comparable to titanium
- no heat treatment is necessary

These properties make DS-Al powders most suitable for aerospace applications.

2. PREPARATION OF DS-AL BILLETS FOR EXTRUSION

Mechanical alloying was performed in a high energy horizontal ball mill at Raufoss Technology AS, Norway, where gas atomised elemental aluminium powder was milled in liquid nitrogen for 3 hours. The DS-Al powder was cold compacted to billets with diameter of 8.3 inches, degassed in vacuum at 620°C and preextruded to rods with diameter of 4.1 inches on the 20MN extrusion press at Raufoss. The rods were cut to 7.9 inches in length. Central holes of the diameter of 1.18 inches were performed in these billets for the indirect extrusion with moving mandrel on the 8MN extrusion press at the Extrusion Research and Development Center of Technical University Berlin, (FZS).

3. EXPERIMENTS

3.1 Experimental equipment

The indirect extrusion of the above mentioned billets was carried out on the 8MN horizontal extrusion press. The material was extruded to tubes by indirect method with moving mandrel [3]. The important advantage of indirect extrusion is the absence of friction between the billet and the container [4]. This guarantees a largely homogeneous flow of the material and an important decrease of the required total extrusion force. The die is located on the front end of a hollow stem and moves relative to the container during the extrusion process. There is no relative movement between the billet and the container. Friction only occurs in the region of the die [5]. Since the deformation takes place uniformly over the entire billet cross-section, this process is best suitable for the high strength powder alloys [6]. To reduce the friction force on the mandrel during the extrusion process, the technology with moving mandrel is preferred. Therfore, to minimise both, total extrusion force and friction force on the mandrel, indirect extrusion with moving mandrel is preferred. In that case the mandrel is attached to the internal piercer and moves with the same velocity as the billet and the container, (Fig. 1). This method ensures the fabrication of seamless tubes with good concentricity. These conditions perfectly fulfil the qualitative requirements of aerospace industry [7]. The extrusion press is equipped with programmable logical controllers which allows to enter the detailed parameters of the process commands variable and offers a broad margin for development in experiments involving technical processes and in their evaluation. For the measurement of axial forces the press employs load cells. By means of a computer-aided measuring and evaluation system, die force and total extrusion force can be determined in relation to the ram displacement. This also applies for recording nominal and actual value of the ram speed, so that narrow tolerance margins in the reproducibility of the experiments can be achieved. (Fig. 1) illustrates schematically the arrangement of measuring elements for indirect extrusion.

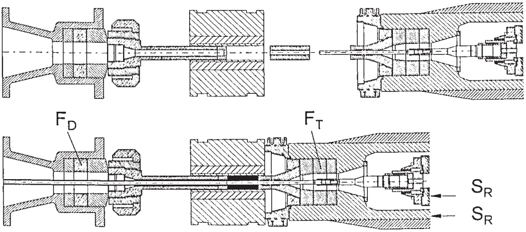

Fig. 1 Indirect extrusion with moving mandrel and the arrangement of measuring elements

F_D= Load cell for measurement of the die force
F_T= Load cell for measurement of the total force
s_R = Measuring element for the ram displacement

3.2 Extrusion conditions

The extrusion conditions are shown below. Container size, container temperature, mandrel size, billet size and billet length were kept constant through all the trials, while billet temperature, die diameter and ram speed were caused to vary.

Container Ø inch	Container temp. °C	Mandrel Ø inch	Billet Ø inch	Bore Ø inch	Billet temp. °C	Die Ø inch	Billet length inch	Product speed in/min.
4.3	490	1.18	4.1	1.18	480-540	1.28, 1.37, 1.46	7.9	126-273

4. RESULTS AND DISCUSSION

4.1 Specific extrusion forces

The correlation between the logarithmic extrusion ratio and the specific extrusion pressure for the billet temperature 520°C and the product speed of 126 in/min is illustrated in (Fig.2). The specific extrusion pressure, that means the relationship of force on the die to billet cross-section area, rises in a direct proportion to the increase in logarithmic extrusion ratio and can be expressed as:

$$\bar{p} = 170.91 \cdot \ln R - 175.53 \qquad (1)$$

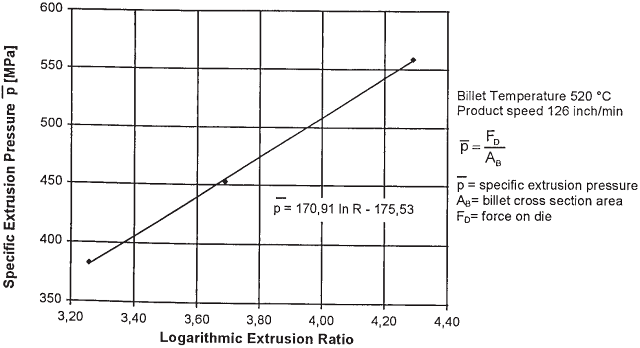

Fig. 2 Correlation between specific extrusion pressure and logarithmic extrusion ratio

The billet temperature has a significant influence on the specific extrusion pressure. With increasing billet temperature the deformation resistance of metal decreases and as a result the specific extrusion pressure also decreases as shown in (Fig.3).

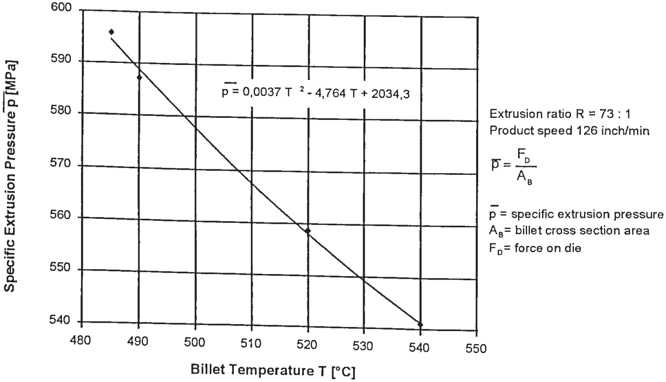

Fig. 3 Effect of billet temperature on specific extrusion pressure

For the extrusion ratio of 73:1 and the product speed of 126 in/min the specific extrusion pressure decreases with increasing billet temperature which can be expressed by the following equation:

$$\bar{p} = 0.0037T^2 - 4.764T + 2034.3 \qquad (2)$$

Ram speed variation has only a small influence on the extrusion force at the unsteady beginning of extrusion. No significant influence of the investigated speed range on the total extrusion force during the steady state of extrusion is measured. However surface roughness decreases slightly with an increase in product speed.

4.2 Mechanical properties after extrusion

Tensile tests on the extrudates with three different wall thickness were carried out at room temperature. Four tensile test samples were taken around the cross-section for each of the three different dimensions. No significant difference around the cross-section was obvious. Only small variations in the strength values of the tubes with different thickness can be seen.

The average values of yield stress, tensile stress and elongation for all the dimensions are given below. The ductility is about 20% which should be promising for cold drawing and bending test.

Temperature °C	Yield Strength $R_{p0.2}$ (MPa)	Tensile Strength R_m (MPa)	Elongation A_5 (%)
Room temp.	167	216	21.4

4.3 Micrographs

The optical micrograph for the as extruded tubes shows homogeneous material with no cracks, pores or pollution. Grains and dispersoids are invisible even after etching due to the very fine structure.

4.4 Bending tests and cold drawing

Sufficient cold bending tests were performed in the range of bending angle 30°, 60°, 90° and 180°. Metallographic investigations of the corresponding cross-sections show neither pores nor cracks. The as extruded tube with O.D. 1.28 inch, I.D. 1.18 inch was reduced by cold drawing in four steps without problems to the required tube with O.D. 0.625 inch, I.D. 0.555 inch.

4.5 Corrosion tests

Corrosion testing, ASTM/B117 designation, has been performed on bended DS-Al tubes after extrusion and cold drawing. Comparision has been made between this tubes and tubes in alloy AA 6061. The specifications of the test were as following:

Temperature: 33.3 - 36.1 °C; ph-value: 6.5 -7.2; NaCl-concentration: 5%.

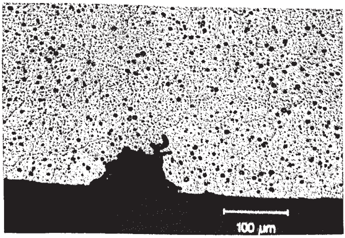

Fig. 4
Etched cross section of AA 6061 tube, tested 1000 h, showing intergranular corrosion

The test results show that after 500 as well as after 1000 hours testing, intergranular corrosion appears outside on the AA6061 tubes. The depth of the corrosion attack has been measured up to 150 µm. No such corrosion has been detected on the DS-Al tubes. The conclusion of the test is that DS-Al is well suited for intergranular corrosion resistant applications in hydraulic tube systems.

5. SUMMARY

- DS-Al was extruded to seamless tubes by indirect extrusion with moving mandrel on the 8MN extrusion press of Extrusion Research and Development Center, Technical University Berlin. Investigations were carried out to determine the influence of billet temperature, extrusion ratio and ram speed on the required extrusion forces.
- A linear dependence of the logarithmic extrusion ratio on the specific extrusion pressure was determined.
- Increase in billet temperature results in parabolic decrease in specific extrusion pressure.
- No significant influence of the investigated ram speed range could be measured on the extrusion force.
- The tensile tests demonstrate no significant variation in the strength values for different wall thickness of the tubes. The average proof stress value is 167 MPa for all the dimensions, the ductility A_5 is about 20%.
- The micrograph of the cross-section shows no pores or cracks.
- Bending and cold drawing tests on the tubes were accomplished with a good success.
- No intergranular corrosion has been detected.

6. REFERENCES

[1] "Mechanical Alloying DS-Al-550", Characteristic physical, chemical, and mechanical properties, Technological datas, Raufoss Technology AS, January 1995

[2] M.Sc E. Hellum, Dr.ing K.E. Moen, "Structural Analysis of a Panel Structure made of Dispersion Strengthened Aluminium", Raufoss Technology AS, Copyright 1995 by the International Astronautical Federation

[3] K. Mueller, Th. Teubert, "Indirect Extrusion of PM-Alloys Al-Si ", Proceedings of the 5th International Conference on Aluminium Alloys, Grenoble, 1-5 July 1996

[4] K. Mueller, "Grundlagen des Strangpressens ", Expert Verlag 1995, ISBN 3-8169-1071-8, Renningen-Malmsheim

[5] K. Mueller, A. Grigoriev, "Direct and Indirect Extrusion of Al-18 SiCuMgNi ", Proceedings of the 4th International Conference on Aluminium Alloys, Atlanta, September 1994

[6] K. Mueller, Ch. Yao, "Some Fundamental Aspects on the Extrusion of Metal Powder Materials", Proceedings of the 4th International Conference on Technology of Plasticity, ICTP, 5-9 September 1993, Beijing

[7] K. Mueller, "Production of Metallic Composite Materials by Indirect Extrusion", Advanced Technology of Plasticity, 1990, Proceedings, Kyoto, 1-6 July 1990