

EUROPEAN COLLABORATION

MAP – Molten Aluminium Purification – end of programme report

Western Europe derives 36% of its aluminium by remelting scrap about 4.5Mt/y. The results of a four-year collaborative programme to improve metal quality derived from scrap were presented in a recent seminar organised by the European Aluminium Association and a call for participants interested in continuing the work made.

The Molten Aluminium Purification (MAP) programme was launched in 2002 and became allied to the European Aluminium Association's 'European Aluminium Technology Platform' (EATP) on its inception in 2005. The objectives of this closely followed the 'roadmap' set out by the US Aluminium Association in 2003. This platform is the European aluminium industry's means for collaborative effort to achieve certain goals for sustainable and competitive production – goals laid out by the EAA in its document 'Vision 2030' which aims to implement them by the year 2030. EATP was launched in 2005 as an evolution from three earlier collaborative programmes (the VIR projects) covering casting, fabrication and forming. These programmes brought together industry, academia and the European Commission to investigate the aluminium production chain, from casting to finished products, to promote sustainability and European competitiveness.

The four-year project on purification MAP was launched in 2002 as a separate project to VIR. At its conclusion, the results were presented at a half-day seminar held in Brussels. In addition to presenting the conclusions, the aim was to further expand the scope of collaboration in a follow-up programme within EATP.

Not all presenters had worked within the MAP project; indeed, that had largely been confined to industry, with little involvement from academic institutions. Thus the aim of the seminar was not only to report on completed work but also to invite presentations from academia, to offer new concepts for tackling the problems and to encourage institutions to work in partnership with industry in the next phase of improving melt quality.

Carl Ludvig Kjelsen, Chairman of the EAA Education & Technology Committee opened proceedings with a presentation on the objectives of EATP and the 'Vision 2030' targets, as well as the state of aluminium recycling in Europe, where close to 36% of the metal is produced from recycled material.

Demand for aluminium within the 25 EU member states has grown to around 11.5Mt, of which recycled metal contributed some 4.5Mt and primary production around 3Mt. The balance is imports (Fig 1).

The often-quoted figure of a 95% saving in energy by remelting scrap rather than producing primary aluminium from the ore provides one reason for the importance of the MAP project. The actual saving can be debated since it depends on the efficiency of the melting furnace and the loss of metal to dross on melting (which can be as high as 10%). On the other hand, it depends whether the energy to produce primary aluminium is simply taken as the pot room consumption (which is typically 13-15kWh/t in a modern smelter) or, if the energy to prepare alumina from the ore and produce pre baked anodes is taken into account (which roughly doubles the total energy required). Whichever the case, the saving is still a significant 90-95% compared with a typical 65% saving for recycling steel (see *Aluminium International Today March/April 2006 p34*). Professor Emeritus U Boin of TUDelft University calculated a lower saving of 89% on melting, using typical energy values of 164MJ/t for primary production and 18MJ/t for secondary.

Mr Kjelsen continued by mapping out targets for further investigation in a follow up to the MAP programme to be launched as Working Group 4 (WG 4). These are:

- reduction of iron contamination;
- reduction of silicon content;
- removal of tramp elements (eg Na, Li, Pb, Bi ...);
- upgrading scrap to smelter grade;
- finding uses for any waste products.

Technologies to be investigated will include filters; degassers; launder systems; plus modelling (eg phase diagram software to predict

microstructure); properties and process software to improve efficiency of molten metal treatment.

MAP involved aluminium companies, academic institutions and research centres; WG 4 would require the involvement of these as well as equipment suppliers, engineering and technology companies, and 'knowledge' companies. A 'Network of Excellence' was proposed to establish an integrated approach to research and development, engaging aluminium companies and academic partners in collaborative R&D to provide the synergy required to exploit the technological potential for the industry.

Prof Boin made a number of predictions:

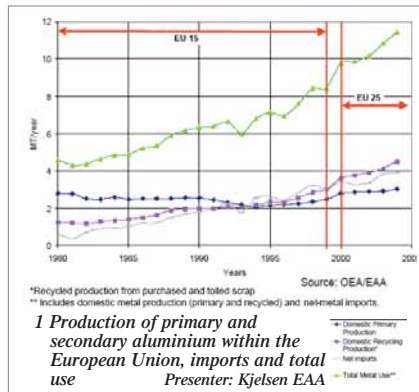
- the price for primary energy in Europe is likely to increase;
- the availability of aluminium scrap in Europe may become critical;
- the European car manufacturers will tend to move east.

He first reviewed world energy reserves pointing out that 62% of the world's 1055bn barrels of known oil reserves were located in the Middle East, that the average annual growth in consumption of oil was 2.5% and, should China reach the same per capita consumption presently experienced in Europe (of 1200kg), then world consumption of oil would double. Also, in the next 10 years, a 50% increase in consumption is forecast. Oil prices were likely to continue to increase reaching as high as \$100/barrel in the long term.

For gas, consumption was growing even more rapidly averaging 6.4%/y globally.

Demand for secondary aluminium from the European car industry would double by 2015 requiring 2.16Mt by then (assuming 0% growth in car production, with output simply keeping pace with population growth). Should demand increase by 1%, consumption of secondary aluminium by the car industry would increase to 2.38Mt. The respective increases in secondary aluminium production to match these scenarios would be 7.7%/y and 8.3%/y.

To meet this demand Prof Boin advocated a more efficient remelting circuit, the 'Integrated Melter' which modeling predicts could improve metal yield by 1.25% to 89.25% over a conventional rotary furnace and reduce



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salt consumption by nearly 50%, generating lower residues for disposal.

Günter Kirchner, secretary general of the Organisation of European Aluminium Refiners and Remelters (OEA) said there has been consolidation within the European remelting and refining industry but the output of casting alloys increased to 2.5Mt/y in 2005 compared with 1.5Mt in 1990. Scrap demand had grown to 1.6Mt in 2005 from 0.45Mt in 1990. However, exports of scrap from Europe have risen sharply, especially to China and India and, in 2005, amounted to 318kt and 118.6kt respectively (Fig 2) of which the UK supplied an estimated 202kt to China. Since 2001, Europe has become a net importer of scrap, with net imports of about 375kt in 2005, sharply up on earlier years.

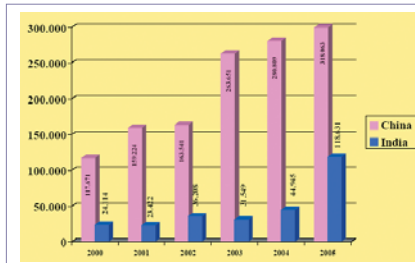
Mr Kirchner calculated that, based on China's present growth in car manufacturing, they would need to import 4400kt of scrap by 2020. Their low labour costs meant that hand sorting was commonly performed on an industrial scale (Fig 3). At present there were no instruments within EU countries to prevent export of this valuable commodity, scrap. It was necessary to lobby governments and the EC to limit scrap exports. Mr Kirchner called for a legal instrument to suspend or to reduce scrap exports for a limited time in the case of a sudden sell out of secondary raw materials similar to the suspension of the trade at stock exchanges. He also called for restrictions on scrap exports if the way to treat and melt scrap in the recipient countries was not in line with European environmental laws.

The EU also claims to be a recycling society and a lot of money is spent to improve the collection and recycling rates. To allow the results of these efforts to be exported is a burden on all EU tax payers.

Prof Derek Fray (Department of Materials Science and Metallurgy, University of Cambridge) addressed available methods of removing of specific elements from aluminium and other non-ferrous metals. These include:

- electrorefining;
- electrorefining using recessed electrodes;
- electrochemical removal of alkali elements by transfer through a solid electrolyte;
- capture of impurities by intercalation compounds.

In laboratory trials, lead and sodium have been successfully removed from aluminium but a possibly more common problem was removal of Mg and Mn present as alloying elements. He took as an example a typical beverage can with a body containing 1.0%Mg + 1.2%Mn and a top containing 2.5%Mg + 0.3%Mn



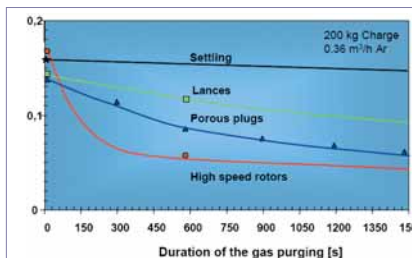
2 Aluminium exports from EU₁₅ to China and India



3 Hand sorting of aluminium alloy scrap in China

| Refining | Target |
|---|---|
| Settling | Separation of less noble elements |
| Gas purging (N ₂ , Ar, Cl ₂) | Separation of H ₂ , O ₂ Floatation of solid inclusions |
| Chlorination (salt treatment, 'solid' Cl) | Separation of alkali metals Floatation of inclusions |
| Filtration | Removal of inclusions |
| Slag treatment | Separation of inclusions |
| Vacuum treatment | Separation of Mg, Zn and Pb |
| Addition of primary Al | Dilution of impurities |
| Addition of Al-alloys | Charge make-up of alloys |

Table 1 Possible treatment of molten aluminium



4 Effectiveness of gas purging methods

from which the resultant melted billet would contain about 1.3%Mg + 1%Mn, requiring minimal blending to be recycled as body stock. Electrolysis was preferred to fractional melting as this yields two valuable products rather than a purified metal and a salt. Technology presently being applied to the manufacture of fuel cells offers possible routes to improved refining of aluminium.

Prof Bernd Friedrich (RWTH – Aachen) spoke on applications which require a high degree of metal cleanliness which includes strip for cans (<0.12mm thick), foil (~6μ), lithography sheet (perfect surface, low H and inclusions) and CD precursor material (extremely low in H and inclusions). Impurities are in the form of solid inclusions – such as refractory particles of Al₄C₃ from the pot line or dissolved as alkaline metals or hydrogen (O₂ and N₂ form a solid oxide and nitride respectively). Table 1 lists the possibilities for treatment of the molten metal.

Various commercially available methods of gas purging were presented and, for hydrogen removal, high speed rotors were found to be the most effective (Fig 4). The principles of filtration and their effectiveness, depending on filter pore size and inclusion size, were also examined (Fig 5).

Prof G J Witkamp (TUDelft), looked at methods of purification by eutectic freeze crystallisation (EFC). This process has been developed for some aqueous solutions to precipitate out a salt from solution by cooling the liquid close to the eutectic temperature. Although not applied to aluminium as yet, Prof Witkamp listed the similarities to water–salt solutions as:

- aluminium is the solvent, impurities are the solutes;
- investigate kinetics of nucleation, growth and agglomeration in suspension and at walls, quantitatively;
- determine metastable zones;
- determine true and pseudo eutectics, and equilibrium distributions;
- observe crystalliser contents.

Dr René Kieft (Corus, The Netherlands) in a collaborative paper with Alcan, Hydro, INPG, Novelis, Remy-Claeys, RWTH(IME), Sintef, TNO and Vito, looked at the need for purification as 70% of the metal presently comes as primary stock – so reaching specification by dilution was common – but concluded that the portion of recycled metal was rising. Recovery should, ideally, be through dismantling but labour costs make this prohibitive although shredding and sorting is the realistic method the demand for more pure raw input material demands for new technologies.

The formation and removal of intermetallics was an effective means of purifying the melt but 'tricks' are needed as the intermetallics are difficult to separate from the molten metal. Partial solidification followed by 'washing out' of the intermetallics was one approach. Applying high pressure (1000 bar), magnetic fields or the addition of trace elements were other means of separating the intermetallics from the melt. Adding trace elements to modify the intermetallic looked the most promising. For example, 0.4%Fe added to a

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melt of shredder waste followed by slow cooling to precipitate large particles produced an intermetallic containing 64% aluminium. Other means of purification were explored in the MAP project with successful results. A new project will possibly be based on these technologies.

Dr Pierre le Brun of Alcan CRV, reported on the collaborative efforts of Alcan, Corus, Hydro, IME, INPG-LTPCM, Novelis, Remi-Claeys Aluminium, Sintef, TNO and Vito which also looked at the formation and removal of intermetallics as a means of purifying the melt. The removal of intermetallics differs greatly from the removal of inclusions, as the volume fraction is some 10000 times higher for intermetallics and the particle characteristics differ in morphology (Fig 6). Separation by settling is successful for several intermetallics if the density difference and particle size is sufficient (Table 2).

Flotation by bubbles is another method relying on collision between bubbles formed by injecting gas deep into the melt and intermetallics but success is dependent on particle size.

Filtration is possible but less cost effective as filters rapidly become clogged and require replacement as the intermetallic volume fraction is high – typically 2-3%. Deep bed filtration (DBF) is too expensive because of this but ceramic foam filters (CFF) are possible and efficiency is enhanced by the formation of a filter cake.

Centrifuging can also be used for large particle sizes but is difficult for small. It is mainly used to treat dross.

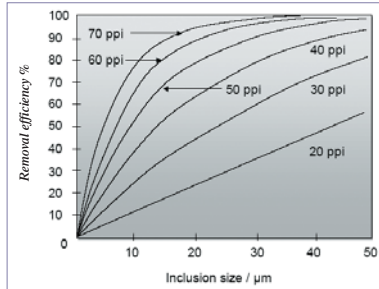
Chemical interaction (eg with Cl_2) to enhance flotation is successful or when using reactive surface filters.

Selective precipitation by inserting a 'cold finger' into the melt is yet another method of removal.

Eutectic solidification requires close temperature control and also the alloys are normally complex so a simple binary phase diagram is unsuitable for selecting temperature accurately. Additional possibilities are magnetic and electro magnetic separation, the use of a cyclone, segregation and displacement washing.

Very frequently, a process will consist of the combination of two steps. Settling is expected to play a significant role as one of these. Temperature control is an important parameter as precipitation of particles is expected to occur in a defined temperature range, in the liquidus–solidus range.

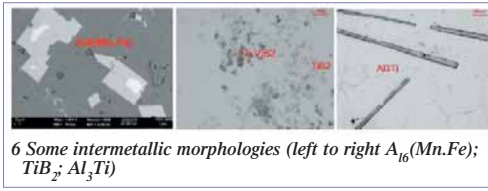
Dr Jochen Schnell (Drache Umwelttechnik) spoke on the principles of filtration, pointing out that the process was purely mechanical so liquids or impurities in the melt cannot be removed. (Strictly some liquids can be removed by a filter if the wetting angle is sufficient but clogging rapidly results).



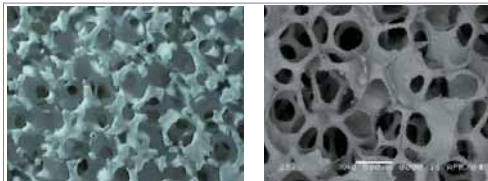
5 Effectiveness of filter pore size (ppi) on removing inclusions
Presenter Friedrich RWTH Aachen

| Intermetallic | Density | % Difference |
|---------------|---------|--------------|
| Al (molten) | 2.4 | - |
| Al_6Mn | 3.3 | 37.5 |
| $Al_{13}Fe_4$ | 3.9 | 62.5 |
| TiB_2 | 4.5 | 87.5 |

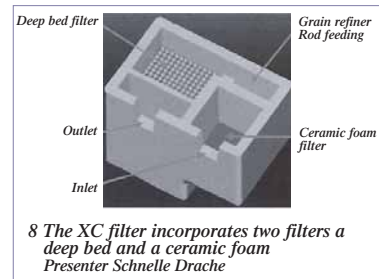
Table 2 Densities of some common inclusions



6 Some intermetallic morphologies (left to right $Al_6(Mn,Fe)$; TiB_2 ; Al_3Ti)



7 Comparison of conventional ceramic foam filter (left) with open pore filter (right)
Presenter Schnelle Drache



8 The XC filter incorporates two filters a deep bed and a ceramic foam
Presenter Schnelle Drache

Deep bed filters (DBF) and ceramic foam filters (CFF) are widely used today, the former being more efficient but requiring more space and being more expensive to replace. Two new systems are currently being tested: Firstly the XC Filter (by VAW/Hydro Aluminium and now produced by Drache), and secondly, filters with improved open porosity obtained by better pregation in the pore forming process. The latter avoids 'blocked' pores present from the manufacturing process in conventional filters, giving a higher filtration efficiency and higher capacity. Furthermore,

higher flow rates can be used.

The XC Filter combines both a DBF and a CFF in a refractory box but has a smaller footprint than a DBF. It also eliminates the negative effect of grain refiner additions on the CFF as the refiner rod is inserted after the CFF but before the DBF (Fig 8).

Future developments are predicted to be: A combination of today's filter technologies but with modified metal flow to provide speed variation. Centrifuging is also expected to play an increasingly important part as are filters with activated surfaces and filter 'aids' for faster and controlled formation of the filter cake.

Dr Georg Rombach (Hydro Aluminium) described tests on continuous crystallisation of intermetallics to remove them by circulating the melt through an external launder to cool it in an attempt to precipitate out intermetallics. Tests on grain refined Al-Ti alloys succeeded in reducing the Ti content from 0.437% to 0.244%. With Al-Fe-Mn, the window of temperature range for precipitation was smaller and only a reduction from 1.81% to 1.75% was achieved. Most of the precipitate formed in the pump chamber, blocking it. Trials on Al-Mn-Fe-Mg showed an even smaller window of opportunity for precipitation. The laboratory scale of the trial was thought to have been a limitation and efforts should be pursued for a commercial-sized trial in which the heat balance could be better controlled and the residence time increased to allow greater precipitation.

Dr W S Miller of Corus summed up the presentations, summarising each of the topics and estimating the cost of putting technologies into practice:

- Proof of concept:
Low cost (€0.1-2M); high risk;
 - Industrialisation:
High cost (€20+M) low risk;
 - Pilot plant:
Medium cost (€5-20M)
medium risk – high relative to cost and the most difficult step.
- The meeting concluded with a call for anyone who wished to be involved in the new programme to express interest to the Education and Technology Committee of the European Aluminium Association, European Aluminium Association, Avenue de Broqueville 12, B-1150, Brussels, Belgium.
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The Power Point presentations are also available on CD from EAA for €15.