Influence of fluxing agent on the quality of recycled Aluminium billets

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Abstract

The quality of aluminium cast billets is highly dependent on the cleanliness of the material. Hydro Extruded Solutions are casting billets in Sjunnen that are delivered for extrusion within the same company. In order to produce extruded profiles of high quality and also maintain the pressing tools, it is a good method to keep the billets as free from inclusions as possible. A fluxing agent in form of salt compounds is used to purify the material during melting, but also to protect it from further oxidation. Another task of fluxing agents is to minimize the aluminium amount in the dross phase.

The purpose of this project was to investigate if the fluxing agent that is used by the cast house is having any impact on the quality of the billets. Therefore, for that purpose, samples with a varying amount of fluxing agent were processed by the cast house in order to be investigated. These samples were investigated with the Optical Microscopy-method in order to determine the area fraction of non-metallic inclusions inside them. The results did not reveal any significant difference in the quality of the different samples since most samples obtained a low OM-index after the investigation. That can be explained by the type of scrap that was used since new scrap is usually very clean and contains smaller amounts of inclusions.

Keywords: Secondary aluminium processing, fluxing agent, inclusion removal, aluminium recycling
Sammanfattning

Kvaliteten hos aluminiumgöt är starkt beroende av renheten i materialet. Hydro Extruded Solutions gjuter rundgöt i Sjunnen, som sedan levereras för strängpressning inom samma företag. För att producera strängpressade profiler av hög kvalitet och även upprätthålla pressverktygen, är en bra metod att hålla göten så fria från inneslutningar som möjligt. Ett flussmedel, i form av saltföreningar, används för att rena materialet under smältningen, men också för att skydda den från vidare oxidation. En annan uppgift som flussmedel har är att minimera mängden aluminium i slaggfasen.

Syftet med detta projekt var att undersöka om flussmedelet som används av omsmältverket har någon inverkan på götkvaliteten. Därför, för detta ändamål har prover med en varierande mängd av flussmedel tillverkats i omsmältverket för att bli undersökte. Dessa prover undersöktes med den Optiskt Mikroskopiska-metoden för att bestämma areafraktionen av icke-metalliska inneslutningar inuti dem. Resultaten avslöjade inte någon signifikant skillnad i kvaliteten hos de olika proverna eftersom de flesta prover erhöll ett lätt OM-index efter undersökningen. Detta kan förklaras av vilken typ av skrot som användes, då process-skrot oftast är väldigt rent och består av mindre mängder inneslutningar.

Nyckelord: Sekundär aluminiumframställning, flussmedel, borttagning av inneslutningar, aluminiumåtervinning
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1 Introduction

1.1 Aluminium

Aluminium is a very commonly used material mostly thanks to its properties and flexibility. It is also the third most abundant element in the earth’s crust, after oxygen and silicon. The combination of aluminium’s lightweight, strength and durability make it a strong candidate for construction applications. Furthermore, the material is resistant to corrosion thanks to a thin oxide layer covering its surface. [1, 2]

1.2 Hydro Extruded Solutions

Hydro is one of the largest companies in the production of aluminium profiles and has also a leading role in innovation. Extruded solutions is one of the five company sections within Hydro. The other four are Bauxite and Alumina, Energy, Primary Metal and Rolled products. The company is located in 40 countries with approximately 100 facilities and almost 23000 employees. [3, 4]

The company is producing aluminium profiles through extrusion. Several aluminium alloys can be used in order to fulfil the desired properties, depending on the application. The profiles can be used in a large variety of applications. Some examples are construction, infrastructure and automotive.

1.3 Recycling and cast house

Aluminium can be processed in two ways. Either by recovering primary aluminium through Bauxite extracts or by recycling. The ability to recycle aluminium is a very big benefit if one considers that only 5% of the energy to produce primary aluminium is needed to produce recycled aluminium. Recycled aluminium is often referred as secondary aluminium. [5]

Sjunnen’s cast house in Vetlanda is producing secondary aluminium billets from scrap material. The final product is then transported to the extruding sections of the company in order to get extruded into profiles. During extrusion, parts of the profiles can get defect and not have the desired properties or shape. These parts will then be sent back for re-melting.

Because of the fact that the billets will be used for extrusion, they need to fulfil some criteria with respect to their quality. They need to be ductile enough in order to maintain the press and its components. The pressing tools can get harm if the billet is of poor quality and that will cause a production break. Apart from that, billets of poor quality may also cause scratches on the surface of the profiles during extrusion. The billets should be free from inclusions and non-metallic impurities, in order to prevent such incidents from happening and keep the billets in good shape.

1.4 Fluxing agent

The best way to keep the material as clean as possible from inclusions and impurities is to remove them from the melt during production. Different salt compounds known as fluxing agents can be used to clean the melt from such particles. The fluxing agent is also used to protect the melt from further oxidation by building a thin layer on the surface between...
the melt and oxygen. Another task of fluxing agents is to recover entrapped aluminium from the dross phase and gain a higher aluminium yield.

1.5 Aim and goals of the project

The aim was to investigate if the fluxing agent that is used by Hydro at Sjunnen’s cast house is having any impact on the quality of the billets. The goal was to examine the material with a varying amount of fluxing agent used. And thereby to make conclusions if the fluxing agent should be used or not. However, the quality of the product was not negotiable.

1.6 Restrictions

This text is mainly focusing on the methods that are used by Hydro and are relevant to the project. Another factor is that tests were executed on a specific cast house during regular production. The circumstances were the same for all the samples.

1.7 Social and ethical aspects

This project is not discussing social or ethical aspects. The usage of fluxing agents in the aluminium processing industry is not having any impact on such aspects. Something that can be counted as social aspect are the health issues that can appear for the workers when using this particular fluxing agent. This will be further discussed in the following section.
2 Theory of Aluminium processing

2.1 Aluminium recycling

Aluminium’s ability to be recycled without undergoing any changes in its properties is responsible for the growth of the recycled aluminium industry. The usage of recycled aluminium products is still growing, as shown in figure 1. Industrial waste, also referred as new scrap, and discarded products are the largest suppliers for such industries. The original procedure to produce aluminium is to recover it from bauxite ores and is frequently termed as primary production. The secondary production differs much from the primary production and has many advantages over it. [5, 6] Such are:

- Energy savings
- Reduced waste disposal
- Reduced emissions
- Reduced capital cost

Figure 1: Total aluminum production and percent from primary and secondary sources. [5]

Figure 2: Typical energy use for primary and secondary aluminum production. [5]
2.2 From scrap to billets

2.2.1 Scrap

Industrial waste in form of recyclable material is mostly referred as *new scrap*. The traditional method for collecting new scrap involves three parties, the dealer, the broker and the processor. The dealer is purchasing scrap from industrial sources and sells it to the broker or the processor. The broker is purchasing scrap from different dealers and sells it to the processor in large quantities. The broker can in that way offer the processor a large variety of scrap in order to suit the processor’s needs. Finally, it is the processor’s job to convert the scrap to a material that can be recycled.

Some of these steps can be avoided, and in that way save money and increase the sustainability by reducing the transportation. This is the big advantage for Hydro who are acting as scrap generators and processors at the same time. Industrial waste from the extruded sections is transported to the cast house which is located close by. However, the scrap generated from the presses might not always be enough to cover the needs of the cast house. This might become a larger issue since the aim of the extrusion industry is to reduce the industrial waste. New scrap is beneficial mostly due to its known composition and the grade of cleanliness. New scrap is cleaner because it has never been put in service. [5, 6]

2.2.2 Melting

One of the most common types of melting furnaces for aluminium recycling is the reverberatory furnace. Natural gases are typically used to fire the furnace, and the heat can thereby be transferred to the metal either by *radiation* or by *convection*. Some of the heat is transferred directly to the metal, while another amount is transported to the metal indirect, by bouncing on the refractory walls. That means that the heat reverberates in other words, which is also how this type of furnace got its name. The ability of aluminium to reflect the heat is greater compared to other metals, which causes the heat to bounce several times between the melt and the walls before it can be absorbed by the melt.

Figure 3: *Cross section of reverberatory melting furnace, illustrating radiation heat transfer.* [5]
The scrap is loaded on a track bound charging machine, which transports it into the melting furnace. The produced dross is removed from the melt and an analysis is performed in order to monitor the composition of the melt. Alloying elements are added if necessary. The melt is transferred (tapped) onwards to the holding furnace when the desired composition is achieved. [5, 6]

2.2.3 Direct Chill Casting

This casting process is semi-continuous and is widely used to produce aluminium billets. The method can be used to process billets of different aluminium alloys and of different diameters. The process is illustrated schematically in figure 4.

The process is initiated when the molten aluminium is poured onto the mould. When the desired amount of molten metal on the mould is reached, a starter block is gradually getting lowered down into a casting pit, carrying the solidified metal with it. The cooling process consists of two mechanisms. The primary cooling is transferring heat from the aluminium melt to the mould because of the cooling water which is circulating in the manifold of the mould. Cooling water is also sprayed on the surface of the billet when it leaves the bottom of the mould. [7]

![Figure 4: DC caster components and cooling regions during steady-state casting. [7]](image)

2.2.4 Homogenisation

The final step of the processing includes the homogenisation of the casted billets. This is done for several reasons. The main reason is to increase the ductility and the workability by transforming βAlFeSi particles into the more workable αAlFeSi phase. Homogenisation is also ensuring the reduce of microsegregation. [8]

A schematic illustration of the total process is shown in figure 5. Where the different numbers stand for: 1; melting furnace, 2; holding furnace, 3; degassing, 4; casting, 5; homogenisation and 6; cutting.
2.3 Requirements on the quality of the billets

The fact that the billets are going to get extruded into profiles, raises some requirements on their quality. [9] Inclusions in the material are undesirable. A high amount of inclusions will eventually cause damage to the pressing tools, but may also harm the surface of the extruded profiles and have a negative impact on the mechanical properties. [10] Therefore, approved billets should have a maximum grade of seven in an Optical Microscopy-test (OM-test). The method for determining the OM-index is described in section 3.2. Other characteristics for a billet of good quality are:

- Correct geometry
- No cracks
- Correct and homogenous composition
- Low amount of dissolved hydrogen

2.4 Hydrogen and inclusions in molten aluminium

2.4.1 Hydrogen

Dissolved hydrogen is one of the most common impurities in molten aluminium and is highly undesired. The hydrogen becomes a problem because of its insolubility in solid aluminium. Dissolved hydrogen in molten aluminium will exsolve during solidification and cause porosity in the material. Dissolved hydrogen can be formed in the melt from the two following reactions:

\[ 3 \text{H}_2\text{O} + 2 \text{Al} = \text{Al}_2\text{O}_3 + 6 \text{H} \]  \hspace{1cm} (1)

\[ \text{H}_2\text{O} + \text{Mg} = \text{MgO} + 2 \text{H} \]  \hspace{1cm} (2)
The reactions are thermodynamically favoured and can only be prevented by the formation of an oxide layer that is covering the surface of the melt. That layer is preventing the contact of the water vapour and the molten metal. These reactions are also driven to the right due to some other factors. Metal turbulence and a higher vapour pressure of water vapour in the atmosphere can encourage the reactions. There is only one working method for purifying the melt from hydrogen. That is to transfer the hydrogen to a gas phase, as shown in this reaction:

\[ 2H = H_2(g) \] (3)

The most commonly used method to achieve this reaction is by reducing the partial pressure of \( H_2 \) in the gas, either by using a vacuum or bubbling gas into the melt. [5, 12, 13]

### 2.4.2 Inclusions

Inclusions can be described as nonmetallic solid particles which are suspended in the melt. The amount of such particles is highly dependent on the quality and the cleanliness of the scrap. Other sources of inclusions can be the refractory materials in the furnace. Inclusions can be formed when refractory particles detach due to reaction with aluminium. *New scrap* usually contain a very low amount of inclusions. Furthermore, the inclusions are divided into two different types, the *exogenous* and *indigenous*. Exogenous inclusions can be found in forms of dirt and oxides in scrap. They are particles that exist as a separate phase before melting. The exogenous particles are much larger compared to the indigenous. That makes them more harmful to the material, but also easier to remove from the melt. Secondary produced aluminium is often less valuable than primary produced aluminium, due to the presence of exogenous inclusions.

Indigenous inclusions are formed by chemical reactions taking place in the melt. Some examples are the formation of alumina, magnesia and spinel accordingly to the following equations:

\[
2Al + 3O = Al_2O_3
\] (4)

\[
Mg + O = MgO
\] (5)

\[
Mg + 2Al + 4O = MgAl_2O_4
\] (6)

Alumina is thermodynamically stable at lower temperatures. Oxygen’s solubility in molten aluminium is also decreasing with the temperature, so the formation of alumina is very natural to occur during cooling. Magnesia and spinel are only formatted in magnesium alloys.

An effective method to remove inclusions from the melt is by *floatation*. The mechanism behind this method is based on the free energy reduction and chemically driven mass transfer. In other words, floatation can be described as inclusion attachment onto bubbles that are rising to the interface. The attached inclusions will eventually float to the surface and be removed. The size of the inclusions plays a significant role in terms of efficiency. Smaller inclusions are more likely to float out.
The same principle can be used in order to purify the melt by using a fluxing agent. The only difference is that instead of bubbles, flux droplets are created in the melt and float to the surface. [5, 10, 12, 14]

2.5 Fluxing

Aluminium scrap has a thin layer of aluminium oxide on its surface. When the scrap is exposed to higher temperatures and gets melted, this layer will grow faster. Furthermore, the aluminium oxide will eventually float to the surface and build the dross phase. The surface tension of the oxide skin will result in aluminium trapped in the dross phase. This is very undesirable since the metal content of the dross can reach up to 80%.

The use of a fluxing agent is therefore needed to recover the aluminium that is trapped in the dross by breaking the oxide layer and releasing the entrapped metal. This is achieved by changing the shape of the aluminium droplets, which are then causing the oxide skin to crack. These kinds of fluxes are based on a standard composition of 50 wt% NaCl and 50 wt% KCl and have a eutectic temperature of about 660°C, as can be observed in figure 6. The addition of fluoride salts is contributing to the coalescence promotion and generation of a flux with much less metal in it. Na₃AlF₆, in particular, is greatly helping to reduce the surface tension.

![Figure 6: Phase diagram of NaCl-KCl.](image)

Apart from recovering the metal from the dross phase, the main tasks of fluxing agents also include: protecting the melt from further oxidation by covering it, and dissolving or suspending dirt, oxides, and other nonmetallic particles. The salt compound droplets act as gas bubbles and suspend inclusions to the surface through floatation. Due to the fact that flux droplets are rising to the surface with a much smaller velocity than gas bubbles, a settling time is required. Apart from that, a settling time of approximately half an hour will allow inclusions to settle to the heel of the furnace, due to density gradients. Bigger and denser inclusions settle faster than smaller and less dense ones. [5, 14, 15, 21]
2.5.1 Stirring

The stirring of the molten metal is of high importance and should be emphasized. By ensuring that the molten metal is well stirred, the following goals can be achieved:

- *Elimination of thermal gradients*: The temperature in the melt can differ from the top to the bottom. This can cause several problems, such as, excessive dross formation and casting difficulties.

- *Elimination of inclusions*: The fluxing agent needs to be well stirred in order to reach the bottom and bring the inclusions on the surface.

- *Higher melt rate*: The heat transfer is improved through stirring, which leads to a melt rate increased by 20% compared to unstirred furnaces.

Furnaces can be equipped with stirring tools. Such tools are *electromagnetic stirrers* and *electromagnetic pumps*. The holding furnace in Sjunnen, where the fluxing agent is added, is stirred manually. This adds importance to the correct stirring treatment. [5, 16]
3 Method

In order to achieve the main goals that were set for this project, a suitable method was required to determine the quality of the billets. First of all, samples were taken from the produced billets that were aimed for investigation. These samples were produced with a varying amount of fluxing agent and were also made of various compositions. The final step of the practical work was to investigate these samples with respect to their inclusion quantity by using the Optical Microscopy-method. The OM-method is described in section 3.4.

3.1 Alloys

Table 1 is listing the alloys that were used for this investigation and their standard compositions. These alloys are included in the 6xxx series. The main elements are, apart from aluminium, magnesium and silicon. This types of compositions contribute to materials with good mechanical properties and good extrusion abilities. [9, 11]

<table>
<thead>
<tr>
<th>Elements</th>
<th>6060</th>
<th>6063</th>
<th>6082</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>0.3-0.6</td>
<td>0.2-0.6</td>
<td>0.7-1.3</td>
</tr>
<tr>
<td>Fe</td>
<td>0.1-0.3</td>
<td>0.35</td>
<td>0.5</td>
</tr>
<tr>
<td>Cu</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Mn</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4-1.0</td>
</tr>
<tr>
<td>Mg</td>
<td>0.35-0.6</td>
<td>0.45-0.9</td>
<td>0.6-1.2</td>
</tr>
<tr>
<td>Cr</td>
<td>0.05</td>
<td>0.1</td>
<td>0.25</td>
</tr>
<tr>
<td>Zn</td>
<td>0.15</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Ti</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Al</td>
<td>Remainder</td>
<td>Remainder</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

3.2 Flux A-412-1

This flux provided by Pyrotek is the actual fluxing agent that is used by the cast house. The composition is listed in table 2. The usage and direct contact with this product can cause health issues. It may cause damage to organs through prolonged or repeated exposure. [17]

<table>
<thead>
<tr>
<th>Chemical symbol</th>
<th>wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₃AlF₆</td>
<td>5-15</td>
</tr>
<tr>
<td>NaCl</td>
<td>40-60</td>
</tr>
<tr>
<td>KCl</td>
<td>40-60</td>
</tr>
</tbody>
</table>

3.3 Procedure description

3.3.1 Tests taken in the cast house

Eleven different batches of billets were processed at the cast house in Sjunnen. The first four batches were treated with full fluxing dosage and correct stirring method. A full
fluxing dosage contains four bags of Flux A-412-1 by Pyrotek, 6kg each. The following five batches were treated with half fluxing dosage, and finally, the last two batches were not treated with a fluxing agent at all. An overview of the number of batches and the fluxing treatment is listed in table 3.

<table>
<thead>
<tr>
<th>Number of batches</th>
<th>Flux dosage</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (180320-2 to 180320-5)</td>
<td>Full</td>
<td>24</td>
</tr>
<tr>
<td>5 (180321-1 to 180321-5)</td>
<td>Half</td>
<td>12</td>
</tr>
<tr>
<td>2 (180322-1 to 180322-2)</td>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3.3.2 Analysis performed in Finspång

A circular disc was cut from each batch in order to be sent for analysis to Finspång. The discs were at that point cut into smaller rectangular pieces with an area of 10 $cm^2$. They were well polished and examined under a light-optical microscope according to the Optical Microscopy-method (OM-method). The optical microscope used was of the brand "Nikon" and model "Eclipse LV150". [18]

### 3.4 The OM-method

This is a metallographic method for quantification of oxide content. It is used for determination of the area fraction of non-metallic inclusions, such as oxide particles in a metallographic sample. The OM-index of each sample is obtained after summarising the total amount of oxide content and dividing it by total inspected area.

The oxide particles have basically two different shapes. They can either appear as compact particles or films. A particle should be larger than 10 $\mu m$ in order to be recorded. If that limit is passed, the length and the width of the particle are documented and used to calculate the area by the length multiplied by the width. After that follows an estimation of the total area that is covered by the particle. That estimation is designated as "\%" in the results section. The primarily calculated area is then multiplied by the factor according to the estimated percentage, and the final estimated area is obtained. The oxide type is estimated by the tone and shape, but other methods can be used for more accurate results. Oxide films are always assumed to have a width of 2 $\mu m$. Figure 7 demonstrates a typical example of how to measure the length and width of a compact oxide particle.
3.5 BQA

"BQA" stands for "billet quality analysis" and is Hydros internal grading for billet quality. There are several more tests taken in order to examine the quality of the billet, and each test is contributing to the total result with one grade. Other tests include inspection of chemical composition, grade of homogenisation, structure and billet surface. The grades are depending on the result of the actual test taken. In the particular case of determining the oxide fraction, the obtained OM-index is then corresponding to a BQA-value. The given BQA-grades have a range from 0 to 5, where 5 indicates the highest possible grade. Table 4 is translating the given OM-indexes to corresponding BQA grades.

Table 4: Flux treatment of different batches

<table>
<thead>
<tr>
<th>OM-index</th>
<th>BQA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 0.99</td>
<td>5</td>
</tr>
<tr>
<td>1 to 1.99</td>
<td>4</td>
</tr>
<tr>
<td>2 to 2.99</td>
<td>3</td>
</tr>
<tr>
<td>3 to 3.99</td>
<td>2</td>
</tr>
<tr>
<td>4 to 6.99</td>
<td>1</td>
</tr>
<tr>
<td>7 or larger</td>
<td>0</td>
</tr>
</tbody>
</table>
4 Results

Eleven different batches were investigated by using the Optical Microscopy-method (OM-method). The OM-index and the billet quality analysis-grade (BQA) are presented for each cast.

4.1 Results of OM-analysis with full flux dosage

Full dosage of Flux A-412-1 was used on the first four samples (180320-2 to 180320-5). The results of the analysis on the quality of the samples are presented in table 5. Examples of oxides found are presented in figure 8.

Table 5: Results of OM-analysis with full flux dosage

<table>
<thead>
<tr>
<th>Cast</th>
<th>Length</th>
<th>Width</th>
<th>%</th>
<th>Area</th>
<th>Type</th>
<th>OM-index</th>
<th>BQA</th>
</tr>
</thead>
<tbody>
<tr>
<td>180320-2 (6060)</td>
<td>85µm</td>
<td>2µm</td>
<td>100%</td>
<td>170µm</td>
<td>AlO</td>
<td>0.17</td>
<td>5</td>
</tr>
<tr>
<td>180320-3 (6060)</td>
<td>15µm</td>
<td>10µm</td>
<td>70%</td>
<td>105µm</td>
<td>AlO</td>
<td>0.11</td>
<td>5</td>
</tr>
<tr>
<td>180320-4 (6060)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td>5</td>
</tr>
<tr>
<td>180320-5 (6063)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td>5</td>
</tr>
</tbody>
</table>

(a) Cast 180320-2 Type: Al₂O₃  
(b) Cast 180320-3 Type: Al₂O₃

Figure 8: Examples of oxides found - 4 bags of Flux A-412-1
4.2 Results of OM-analysis with half flux dosage

Half dosage of Flux A-412-1 was used on the following five samples (180321-1 to 180321-5). The results of the analysis on the quality of the samples are presented in table 6. Examples of oxides found are presented in figure 9.

Table 6: Results of OM-analysis with half flux dosage

<table>
<thead>
<tr>
<th>Cast</th>
<th>Length</th>
<th>Width</th>
<th>%</th>
<th>Area</th>
<th>Type</th>
<th>OM-index</th>
<th>BQA</th>
</tr>
</thead>
<tbody>
<tr>
<td>180321-1 (6063)</td>
<td>20µm</td>
<td>35µm</td>
<td>100%</td>
<td>700µm</td>
<td>MgO</td>
<td>0.70</td>
<td>5</td>
</tr>
<tr>
<td>180321-2 (6063)</td>
<td>80µm</td>
<td>20µm</td>
<td>70%</td>
<td>1120µm</td>
<td>AlO</td>
<td>1.64</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>110µm</td>
<td>2µm</td>
<td>100%</td>
<td>220µm</td>
<td>AlO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>150µm</td>
<td>2µm</td>
<td>100%</td>
<td>300µm</td>
<td>AlO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180321-3 (6063)</td>
<td>160µm</td>
<td>6µm</td>
<td>100%</td>
<td>960µm</td>
<td>AlO</td>
<td>2.71</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>100µm</td>
<td>15µm</td>
<td>100%</td>
<td>1500µm</td>
<td>MgO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25µm</td>
<td>10µm</td>
<td>100%</td>
<td>250µm</td>
<td>TiB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180321-4 (6063)</td>
<td>40µm</td>
<td>2µm</td>
<td>100%</td>
<td>80µm</td>
<td>AlO</td>
<td>0.01</td>
<td>5</td>
</tr>
<tr>
<td>180321-5 (6063)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 9: Examples of oxides found - 2 bags of Flux A-412-1
4.3 Results of OM-analysis with no flux

No amount of Flux A-412-1 was used on the last two samples (180322-1 and 180322-2). The results of the analysis on the quality of the samples are presented in table 7. Examples of oxides found are presented in figure 10.

<table>
<thead>
<tr>
<th>Cast</th>
<th>Length</th>
<th>Width</th>
<th>%</th>
<th>Area</th>
<th>Type</th>
<th>OM-index</th>
<th>BQA</th>
</tr>
</thead>
<tbody>
<tr>
<td>180322-1 (6082)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.00</td>
<td>5</td>
</tr>
<tr>
<td>180322-2 (6082)</td>
<td>5µm</td>
<td>15µm</td>
<td>100%</td>
<td>75µm</td>
<td>AlO</td>
<td>0.28</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>20µm</td>
<td>20µm</td>
<td>20%</td>
<td>200µm</td>
<td>MgO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Cast: 180322-2 Type: MgO
(b) Cast: 180322-2 Type: Al₂O₃

Figure 10: Examples of oxides found - No bags of Flux A-412-1

4.4 Statistics

The meanvalues of the OM- and BQA-analysis were calculated, depending on the amount of fluxing agent used. The relationships between the different meanvalues are presented in figures 11 and 12.
Figure 11: OM-meanvalue dependence with respect to the amount of fluxing agent used

Figure 12: BQA-meanvalue dependence with respect to the amount of fluxing agent used
5 Discussion

5.1 Inclusion rates in the samples

Apart from some minor fluctuations, no significant differences were found in the quality of the samples. The obtained Optical Microscopy indexes are not revealing any difference in the sample quality regardless the amount of fluxing agent that was used.

It can be observed in the results that the inclusion rates are generally low in all different cast types, despite the limited statistics. This observation can be even clearer when results from similar studies are reviewed. It has been proven in similar investigations, but under different circumstances, that the usage of this particular fluxing agent (Flux A-412-1) is contributing to high grades of inclusion removal in holding furnaces. The higher OM-values of batches 180321-2 and 180321-3 can be explained by the type of scrap that has been used. [19]

5.2 MgO inclusions

According to the results, the amount of MgO inclusions has been shown to increase in batches without full dosage of fluxing agent. That can be explained by the lack of this particular fluxing agent since earlier investigations are showing that this particular fluxing agent is responsible for suspending magnesium from the melt. [20] That can be described by equation 7, where Na$_3$AlF$_6$ is reacting with Mg and forming 2 NaMgF$_3$:

\[
2 \text{Mg} + \text{Na}_3\text{AlF}_6 \rightarrow 2 \text{NaMgF}_3 + \text{Na} + \text{Al}
\] (7)

5.3 Scrap

The scrap sources are mainly responsible for the cleanliness of the samples in this study. New scrap is very clean and contains a low amount of inclusions. So the usage of fluxing agents become more important when the material consists of higher inclusion rates. The exact scrap sources of the batches that were processed for this project are unknown. The cast house is receiving scrap internal from the extrusion sections but is also purchasing scrap from other suppliers. So the used scrap is of unknown quality.

5.4 Dross

The use of fluxing agents is also highly promoted in order to recover aluminium from the dross. Especially fluoride additives such as Na$_3$AlF$_6$, which can be found in Flux A-412-1, are contributing to metal droplet coalescence and aluminium recovery. Therefore the metal loss without the use of any fluxing agent should be considered and compared to the cost of flux usage. [5, 21]

5.5 Other parameters

Another study has pointed out the importance of correct fluxing temperature. It is being said that fluxing temperatures under 700°C will not be very efficient. The optimum fluxing temperature based on that research is 740 °C. Higher fluxing temperatures are not desired either since hydrogen absorption in molten aluminium is being accelerated at temperatures about 790 °C. [21]

Alloying elements can also lead to inclusion formation in form of indigenous inclusions. So alloys that contain higher grades of alloying elements may have a bigger need for use of a fluxing agent.
As explained earlier, inclusions can also be removed through sedimentation by giving them the time to settle down to the heel of the furnace. It has been shown in similar studies as the previously discussed, that longer settling times are working in favour of inclusion removal. In this study, all batches were processed with a settling time of forty-five minutes.

5.6 Error sources

It should be emphasized that the obtained results are also depending on error sources. The sample area that has been investigated is very small in comparison to the total volume of the billet. The values that are obtained should therefore only be treated as indications, since other parts of the billets may be cleaner or dirtier with respect to inclusions.

It should also be mentioned that the statistics are limited, especially for the cases that were not treated with a fluxing agent. Therefore, once again, these results can only be treated as indications and inspiration for further investigations.
6 Conclusions and recommendations for further research

By obtaining and discussing the results of the tests made, the following can be concluded:

- The scrap source plays a significant role in the cleanliness of the final product. If the scrap is very clean, the fluxing agent will not have many inclusions to dissolve or suspend from the melt. Although minor fluctuations can occur in the quality.

- One of the main tasks of fluxing agents is to recover and release aluminium from the dross phase. This is very important and should be tested and quantified in order to make sure if the usage of fluxing agents is beneficial or not with respect to costs.

- Further studies are required in order to get a better understanding whether the fluxing agent is useful or not. A suggestion is to begin with inspecting the amount of metal in drosses without a fluxing agent. If the use of a fluxing agent is more beneficial in terms of money, no further investigation is needed. If not, another suggestion is to examine the influence of fluxing agents on different scrap types and alloys. Alloying elements can also cause increased inclusion concentrations. The fluxing agent could then probably be reduced if there is no need for it on clean scrap.
7 Acknowledgements

The author’s gratitude is expressed towards the project’s supervisors Prof. Anders Eliasson from Royal Institute of Technology and process engineer Oskar Altzar from Hydro Extrusion Sweden. Their guidance and help throughout the project made it possible to finish this work.
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8 References

[2018-04-23]

[2018-04-23]

[2018-05-21]

[2018-04-23]


[14] Technology Strategy Consultants, "Inclusion removal (1) - furnace operations (fluxing, settling)", PowerPoint file


[18] Information gained from field studies in Finspång, 2018

