Knowledge Mapping to explore the influence of Billet Quality on extrusion plant efficiency

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Introduction

Now more then ever, in this challenging business environment, aluminium extruders are one of many downstream businesses examining opportunities for cost reduction and efficiency improvement within their operations. One important aspect of this is ensuring a consistent source of good quality input materials, such as extrusion billet. During the years of high growth this frequently meant evaluating billet from new suppliers in low-cost manufacturing regions, such as China, while in the current economic climate there is the need to evaluate different sources of billet as a consequence of a number of recently announced smelter closures and the associated disruption of billet supply that this brings.

While it has long been recognised that billet quality is an important aspect of extrusion plant performance, it has not always been easy for the extruders to prioritise where valuable resources should be focussed when trying to improve the efficiency of an extrusion plant. Through the use of knowledge mapping it is possible to clearly understand the impact of billet quality on extrusion plant performance and then focus on evaluating those key aspects of billet quality that can impact plant output and efficiency, using the methodology outlined below.

Knowledge Mapping

Innoval Technology uses a powerful, yet simple, approach to identify the most important process stages affecting the characteristics (or attributes) of an extrusion plant by constructing a matrix, as shown in Figure 1, known as a Knowledge Map (or K-Map). This is built by breaking down the process of extruding into discrete stages on the axis across the top and then listing the important attributes of operating an extrusion plant, which are listed down the side. These attributes cover both the quality of the product as required by the customer, such as dimension, surface and mechanical properties, as well as factors which impact the economics of the overall plant operation. For demonstration purposes this list has been kept short, but many more attributes can be added if required. The process stages could also be expanded to cover a greater number, but again has been kept simple in this example in order to focus on the 4 stages on the left of the list which make up billet supply; Alloy composition, Molten metal treatment, DC casting and Homogenisation. This particular K-Map is a generic map appropriate to a gas fired log furnace followed by a hot billet shear or saw which is feeding a direct extrusion press producing soft alloy profiles.

The K-Map then shows where each of the process stages has an effect on the attributes of the extrusion operation, which is indicated by a coloured square. In order to rank the relative importance of each process stage on each of the attributes, colour coding is introduced to show strong, medium and weak interactions, as indicated in the legend. The K-Map also allows for any disputed or unknown relationships to be captured but these are not required in this example. It is important to realise that the strength of the relationships can be compared across the rows of the matrix in order to assess the relative importance of each process stage on that particular attribute. This approach is similar to that used in a Quality Function Deployment (QFD) matrix, but uses colour coding instead of numerical ratings.

Although the top level matrix is of itself a powerful tool to carry out a structured and repeatable assessment of an extrusion plant, the real strength lies in knowing why a particular process stage affects an attribute, since this is the transferable knowledge that can be used during a technical audit of any extrusion plant and can help identify the specific areas of focus for process improvement activities. This information can be captured and stored in Level 2 of the software developed by Innoval Technology. However, for the purposes of this article we will concentrate on those billet-related issues identified to be at least as important as some of the process stages that are within the control of the extruder.

Stage of Billet Manufacture

The stages which are used to describe billet manufacture in the K-Map are in fact each made up of many separate steps, but are grouped together here for simplicity. For example, if a more detailed knowledge-map of extrusion billet was required, it would be possible to break down the stages into the numerous relevant steps as follows;

- Alloy composition - Si, Fe, Cu, Mn, Mg, Cr, Zn, Ti, trace elements.
- Molten metal treatment - degassing, filtration, grain refinement.
- DC casting - launder materials, casting technology, casting conditions.
- Homogenisation - batch or continuous, peak metal temperature, time at temperature, cooling rate.

Composition affects Performance

The K-Map (Figure 1) shows that alloy composition has a relatively important effect on several attributes. The strong effect of composition on tensile strength is no surprise, since this is the reason why many 6000-series alloy variants exist with their differing levels of Mg and Si; their principal role being to provide strengthening via the volume fraction of fine Mg_2Si particles which form during age hardening. However, one of the key aspects is to achieve *consistency* of strength which, in part, is about controlling the range of alloying additions made. Although the composition of an alloy can fall within the 6060 composition, the T5 temper UTS can be in the range 150 to 270 MPa [1], which would clearly be unacceptable for many end-use applications. The effect of Cu, Mn, Cr and other trace elements on strength also emphasises the need for tighter composition tolerances than those shown in the ISO specifications. Typically this needs to be ±0.02 wt.% for the major alloying elements.

The other more important influences of alloy composition are the effects on the surface attributes of the extrusion, i.e., surface pick-up and surface tearing. These influences can perhaps best be demonstrated in the extrusion window diagram [2] as shown in Figure 2. At high billet temperatures and extrusion speeds the surface starts to deteriorate, initially because of pick-up and then via tearing and eventually surface melting. Moving to a more dilute alloy shifts the limiting conditions to higher speeds, thus increasing tonnes per hour (subject to the other factors indicated in the K-Map).

However, there is also an important mechanism caused by the intermetallic particles in the billet which form during DC casting as the β-phase and can then transform to the α-phase during homogenisation. Some of the influences of alloy composition on pick-up are shown in Figure 3 which illustrates how increasing the Si content of the alloy gives pick-up at lower extrusion speeds [3]: this is as a consequence of Si encouraging the formation of the Si-rich β-phase. Figure 3 also shows the effect of increasing Mn on reducing pick-up, even at the highest extrusion speeds used, which occurs because Mn is an α-phase stabiliser. Typically, it is desirable that at least 70% of the intermetallics are the α-phase although, as the K-Map shows, there are many other influences on the surface attributes and there is no cut-off below which quality necessarily deteriorates.

Homogenisation affects Performance

The other important influence of billet quality comes via the homogenisation stage as a consequence of both the β to α transformation and the dissolution and precipitation of the Mg_2Si phase. The extent of the transformation of β to α intermetallics is controlled by the time and temperature experienced during billet homogenisation, which in turn affects surface pick-up and surface tearing, as described previously. It is important to measure the consistency of this transformation since it is possible to have significant variation both across the billet section and along the length, as shown in Figure 4. This variability can arise as a consequence of furnace control and can vary significantly between pusher and batch furnaces.

Another important influence is on tensile strength, where the homogenisation conditions will influence both the extent of dissolution of the as-cast Mg_2Si and the re-precipitation of a much finer distribution of Mg_2Si during controlled cooling to room temperature. If the billet is cooled too rapidly, the Mg_2Si is too coarse to re-dissolve during the extrusion cycle and therefore prevents the Mg and Si being available to take part in the subsequent age hardening stage. The Mg_2Si distribution in the as-homogenised billet can readily be imaged in an SEM (Figure 5) and the particle size distribution quantified.

There are other lesser effects which can be caused by both details of the alloy composition and homogenisation, principally as a consequence of their effect on flow stress and its associated influence on metal flow through the die during the extrusion cycle; although as shown in the K-Map, the effects are only weak in comparison to the other more significant stages within the extrusion plant.

Metal Treatment and Casting Effects

There are also some relatively weak effects which can be introduced during molten metal treatments and DC casting. These are caused principally by the presence of inclusions or entrapped oxide films (in the case of die lines) and by any internal cracking within the ingot that may not be fully healed during extrusion.

There are several pieces of equipment which can be used to measure molten metal cleanliness both during casting and on re-melting of a billet sample. An example is the Prefil® method [4] , which as well as being capable of quantifying the metal cleanliness also has the advantage of allowing the type of inclusions to be subsequently analysed in order to determine their origin and appropriate corrective actions to be taken in the cast house.

Summary

The K-Map of the extrusion plant highlights the more critical and important process stages that are within the control of the extruder and their influence on the quality and economic outputs of the plant. However, billet quality is also an important input that frequently is outside the control of the extruder. Assessment of billet quality is an important step in control of this input but, in addition, extruders and billet suppliers need to work in partnership to ensure they have systems in place to ensure quality consistently meets extruders' needs. Independent audits and experimental evaluations are a critical part of that relationship and these are services offered by Innoval Technology. Clearly, to run an efficient plant extruders should not only rely on the lowest cost suppliers and, for the billet suppliers, evidence of high quality can be used as a product differentiator, especially in these challenging market conditions.

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4. see Prefil®-Footprinter at www.abb.com

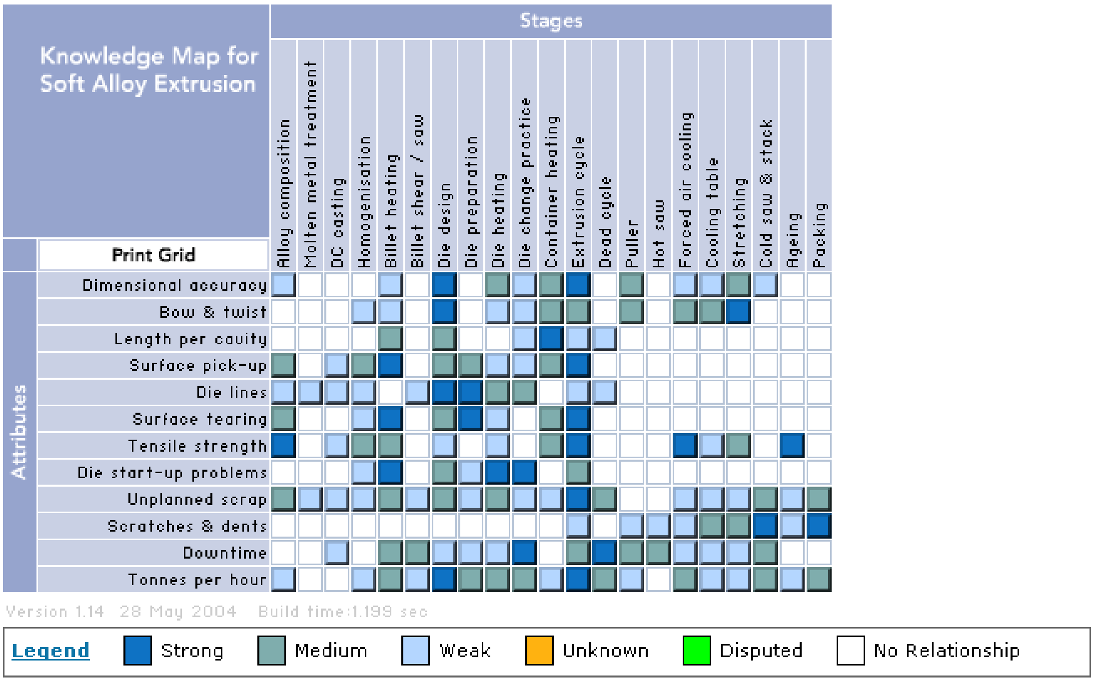

Figure 1: Generic K-Map for a soft alloy extrusion plant using Innoval Technology's proprietary software.

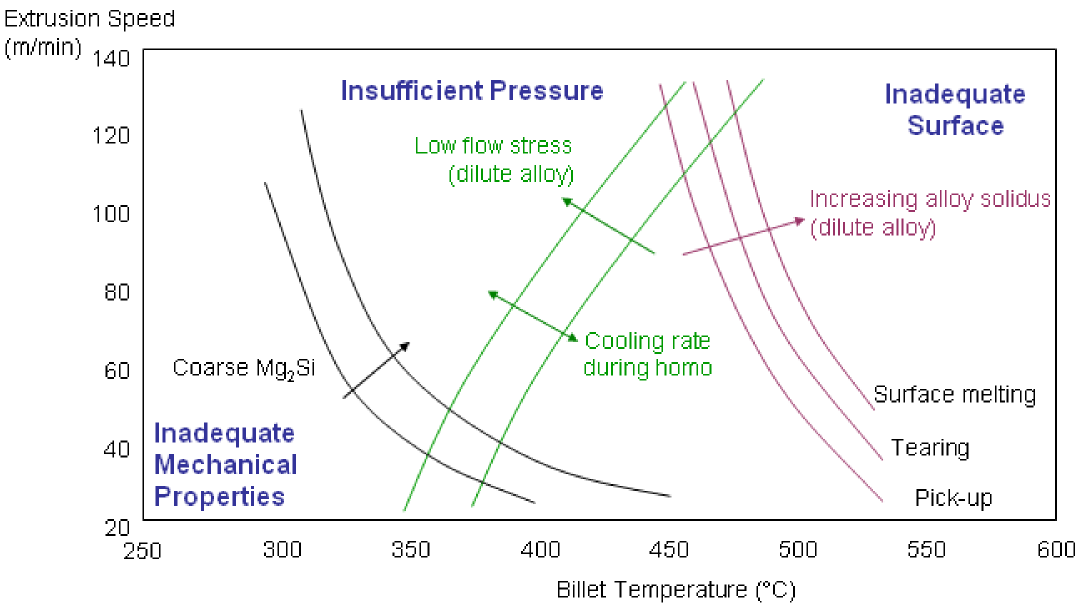

Figure 2: Effect of composition and homogenisation on extrusion window.

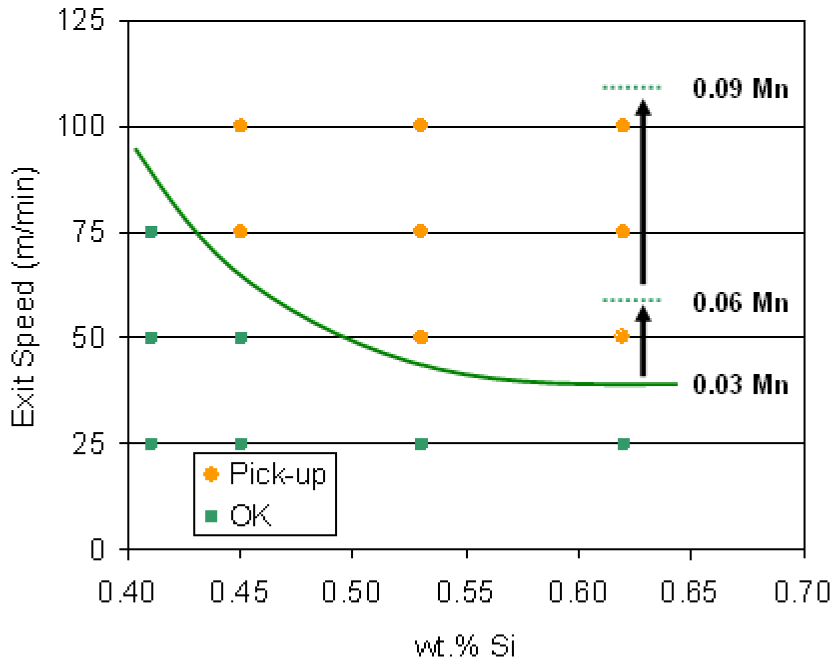

Figure 3: Effect of Si and Mn on onset of surface pick-up.

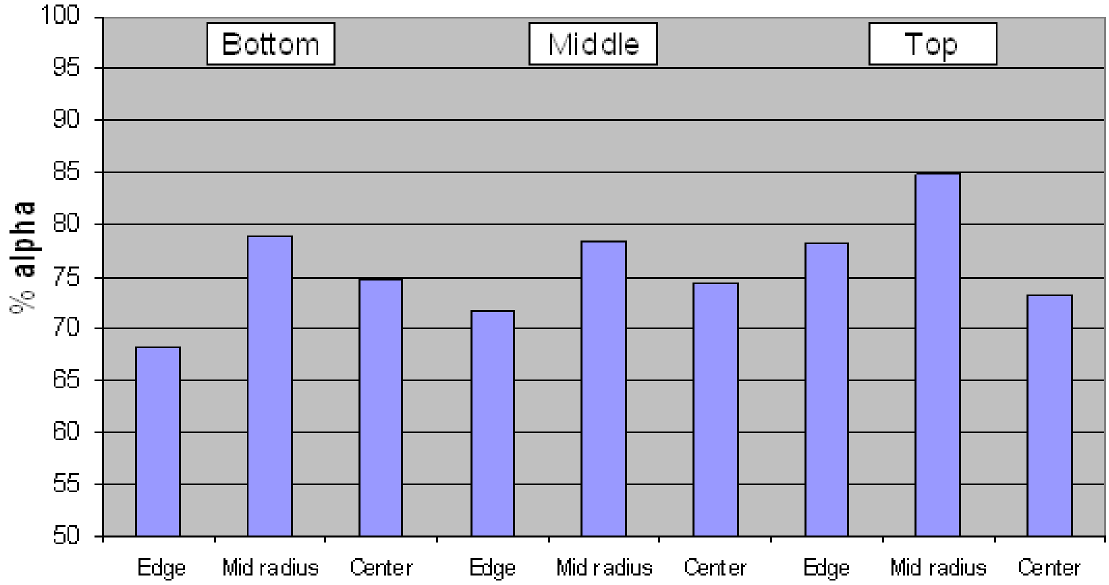

Figure 4: Variation in intermetallics through a homogenised 6063 log.

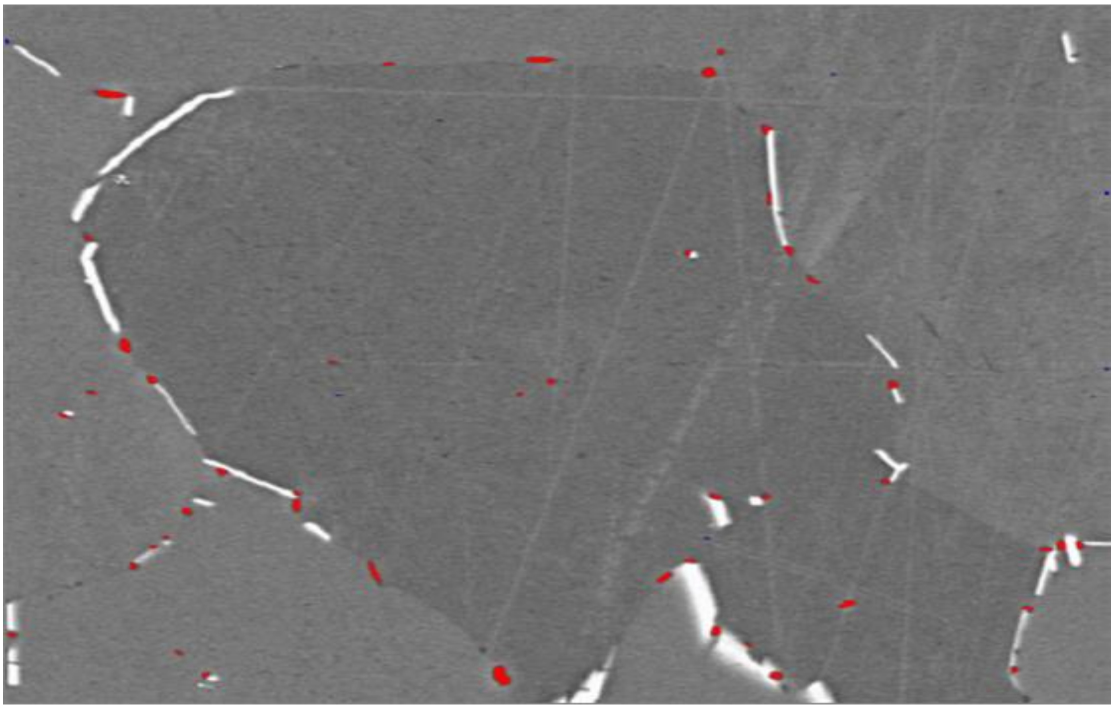

Figure 5: Micrograph showing Mg_2Si (coloured red) and Fe-rich (white) intermetallics in billet.