Achieve a good quality melt

1.1 Background

It is a requirement that either the process for the production and treatment of the melt shall have been shown to produce good quality liquid, or the melt should be demonstrated to be of good quality, or, preferably, both. A good quality liquid is one that is defined as

(i) Substantially free from suspensions of non-metallic inclusions in general, and bifilms in particular.
(ii) Relative freedom from bifilm-opening agents. These include gas in solution and certain alloy impurities (such as Fe in Al alloys) in solution.

It should be noted that such melts are not to be assumed, and, without proper treatment, are probably rare. (Additional requirements, not part of this specification, may also be placed on the melt. For instance, low values of particular solute impurities that have no effect on bifilms.)

Unfortunately, many melts start life with poor, sometimes grossly poor, quality in terms of content of suspended bifilms. Figure 1.1 gives several examples of different poor qualities of liquid aluminium alloy. The figures show results from reduced pressure test (RPT) samples observed by X-ray radiography. Since the samples are solidified under only one tenth of an atmosphere (76 mm compared to 760 mm of full atmospheric pressure) any gas-containing defects, such as bubbles, or bifilms with air occluded in the centres of their sandwich structures, will be expanded by ten times. Thus rather small defects can become visible for the first time.

We can assume [following the conclusions of Castings (2003)] that bifilms always initiate pores, and that the formation of rounded pores simply occurs as a result of the bifilms being opened by excess precipitation of gas, finally achieving a diameter greater than its original length. Thus the RPT is an admirably simple device for assessing (i) the number of bifilms, but (ii) gas content is assessed by the degree of opening of the bifilms from thin crack-like forms to fairly spherical pores.

If the melt contained no gas-containing defects the radiographs would be clear.

However, as we can see immediately, and without any benefit of complex or expensive equipment, the melts recorded in Figure 1.1 are far from this desirable condition. Figure (a) shows a melt with small rounded pores indicating that the bifilms that initiated these defects were particularly small, of the order of 0.1 mm or less. The density of these defects, however, was high, between 10 and 100 defects per cm$^3$.

Sample (b) has a similar defect distribution, but with slightly higher hydrogen content. Sample (c) illustrates a melt that displayed a deep shrinkage pipe, normally interpreted to mean good quality, but showing that it contained a scattering of larger pores, probably as a result of fewer bifilms, so that the available gas was concentrated on the fewer available sites. Melt (d) has considerably larger bifilms, of size in the region of 5 mm in length, and in a concentration of approximately 1 per cm$^3$. Samples (e) and (f) show similar samples but with increasing gas contents that have inflated these larger bifilms to reasonably equiaxed pores.

Naturally, it would be of little use for the casting engineer to go to great lengths to adopt the best designs of filling and feeding systems if the original melt was so poor that a good casting could not be made from it.
Thus this section deals with some of the aspects of obtaining a good quality melt. It should be noted that many of these aspects have been already been touched upon in Castings (2003).

In some circumstances it may not be necessary to reduce both bifilms and bifilm-opening agents. An interesting possibility for future specifications for aluminium alloy castings (where residual gas in supersaturated solution does not appear to be harmful) is that a double requirement may be made for the content of dissolved gas in the melt to be high, but the percentage of gas porosity to be low. The meeting of this double requirement will ensure to the customer that bifilms are not present. Thus these damaging but undetectable defects will, if present, be effectively labelled and made visible on X-ray radiographs and polished sections by the precipitation of dissolved gas. It is appreciated that such a stringent specification might be viewed with dismay by present suppliers. However, at the present time we have mainly only rather poor technology, making such quality levels out of reach.

(For steels, the content of hydrogen is a more serious matter, especially if the section thickness of the casting is large. In some steel castings of section thickness above about 100 mm or so, the hydrogen cannot escape by diffusion during the time available for cooling or during the time of any subsequent heat treatments. Thus the high hydrogen content retained in these heavy sections can lead to hydrogen embrittlement, and catastrophic failure of the section by cracking.)

The possible future production of Al alloys for aerospace, with high hydrogen content but low porosity, is a fascinating challenge. As our technology improves such castings may be found not only to be manufacturable, but offer guaranteed reliability of fatigue life, and therefore command a premium price.

The prospect of producing ultra-clean Al alloys that can be demonstrated in this way to be actually extremely clean, raises the issue of contamination of the liquid alloy from the normal metallurgical additions such as the various master alloys, and grain refiners, modifiers, etc. It may be that for clean material, normal metallurgical additions to achieve refinement of various kinds will be found unnecessary, and possibly even counter-productive.

For ductile iron production the massive amounts of turbulence that accompany the addition of magnesium in some form, such as magnesium ferro-silicon, are almost certainly highly damaging to the liquid metal. It is expected that immediately after such nodularization treatment that the melt will be massively dirty. It will be useful therefore to ensure that the melt can dwell for sufficient time for the entrained magnesium-oxide-rich films to float out. The situation is analogous to the treatment of cast iron with CaSi to effect inoculation (i.e. to achieve a uniform distribution of graphite of desirable form). In this case the volume of calcium-oxide-rich films is well known, so that the CaSi treatment is known as a ‘dirty’ treatment compared to FeSi inoculation. The author is unsure about in-mould treatments therefore with such oxidizable elements as Ca and Mg. Do they give results as good as external treatments? If so, how is this possible? Some work to clarify this situation would be valuable.

For nickel-based superalloys melted and cast in vacuum, it is with regret that the material is, despite its apparently clean melting environment, found to be sometimes as crammed with
oxides (and/or nitrides) as an aluminium alloy (Rashid and Campbell 2004). This is because the main alloying element in such alloys is aluminium, and the high temperature favours rapid formation and thickening of the surface film on the liquid. This occurs even in vacuum, because the vacuum is only, of course, dilute air. Although thermodynamics indicates that aluminium oxide (and perhaps also the nitride) is unstable in vacuum, there is no doubt that a film forms rapidly, and can become entrained, thus damaging the liquid and any subsequent casting. The melting and pouring processes of these alloys also leaves much to be desired. The alloy is melted by induction, and is poured under gravity via a series of sloping launders, falling several times, and finally falling one or two metres or more into steel tubes that act as moulds. This awfully turbulent primary production process for the alloy impairs all the downstream products.

A recent move towards the production of Ni-base alloy bar by horizontal continuous casting is to be welcomed as the first step towards a more appropriate production technique for these key ingredients of our modern aircraft turbines. Production of improved material is currently limited, but should be the subject of demand from customers. Poor casting technology has been the accepted norm within the aircraft industry for too long. (However, as we all know, the aircraft industry is not alone.)

1.2 Melting

The quality of melts can be significantly affected by the type of melting furnace. For instance the melting of the charge in a single pot is usual. Furnaces of this type automatically ensure that all the oxides on the surface of the charge material will be incorporated into the melt. Thus crucible furnaces, whether bale-out or tilting, or whether heated by gas or electrical resistance, are all of this type. Also included are induction furnaces and reveratory (meaning reflected heat from a roof) melting units.

The remelting of aluminium alloy sand castings probably represents one of the worst cases, since the oxide skin on a sand casting is particularly thick, having cooled from high temperature in a reactive environment. When the skin is submerged in the melt it can float about, substantially complete. When remelting scrapped cylinder heads by adding them in to one end of a combined melting and holding furnace, the author has fished out the skin of a complete cylinder head from the opposite end.

The remelting of aluminium alloy gravity die (permanent moulded) castings have an oxide skin that is much thinner, and seems to give less problems. Whether this is a real or imagined advantage in view of the damage that can be caused by any entrained oxide skin, irrespective of its thickness, is not clear at this time.

Induction furnaces enjoy the great advantage of extremely rapid melting. However, they have long been regarded with some reserve by aluminium melters because of the electromagnetic stirring, with the suspicion that oxides may therefore be entrained. With normal inductive coil geometry there is a high-pressure region near the centre of the wall that drives a double torroid (a torroid is a ring shape like a doughnut) in directions away from this point. However, there is no evidence known to the author that the stirring is sufficiently rapid to entrain oxide, although such a problem cannot be ruled out. What is certain is that any oxide will have no opportunity to settle out, but this is also true of most of the above crucible furnaces because of the presence of natural convection. Because of the heat input via the walls of the crucible, and heat loss from the top surface, the convective stirring will be expected to take the form of a simple torroid, the flow direction being upwards at the wall, and downwards in the centre. The only significant difference, if any, between these two stirring modes is the rate of stirring. It is possible that the higher energy in the induction furnace may shred films, whereas the natural convective regimes in other furnaces would be expected to conserve the original film size distribution.

The dry hearth type of furnace is quite different. The charge to be melted is heaped onto a dry, sloping refractory floor, called a hearth. As the charge melts, the liquid alloy flows out of its oxide skin and down the sloping hearth into the main melt. The oxide skins present on the surface of the charge materials remain behind, accumulating on the hearth. The pile of dross is raked off the hearth at intervals via a side door. Such melting units are useful in aluminium and copper alloy production.

1.3 Holding

Holding furnaces can also have a significant effect on melt quality. Holding furnaces were originally selected for their utility in smoothing the supply of molten metal between batch melters and a fluctuating demand from the casting requirements. An additional advantage was the smoothing of temperature and chemical analysis that was unavoidably variable from batch to batch.
The Cosworth Process was perhaps the first to acknowledge that for liquid aluminium alloys the oxide inclusions in a holding furnace could be encouraged to separate simply by a sink and float principle; the metal for casting being taken by a pump from a point at about midway depth where the best quality metal was to be expected.

In contrast, the holding of melts in closed vessels for the low-pressure die casting of aluminium, or the dosing of the liquid metal, are usually impaired by the initial turbulent pour of the melt to fill the furnace. The total pour height is often of the order of a metre. Not only are new oxides folded into the melt in this pouring action, but those oxides that have settled to the floor of the furnace since the last filling operation are stirred into the melt once again. Finally, these enclosed units suffer from the inaccessibility of the melt. This usually restricts any thorough action to improve the melt by any kind of degassing technique.

The Alotech approach to the design of a holding furnace is patented and not available for publication at the time of writing. It is hoped to rectify this in future editions of this work as details of the process are published. Why even mention it at this stage? The purpose of mentioning it here is to illustrate that even apparently simple equipment such as a holding furnace is capable of considerable sophistication, leading to the production of greatly improved processing and products. It takes the concept of melt cleaning and degassing to an ultimate level that probably represents a limit to what can be achieved. In addition, the technique is simple, low capital cost, low running cost, has no moving parts and is operator-free. At this time the technique is being applied only to aluminium alloys.

1.4 Pouring

Most foundries handle their metal from one point to another by ladle. The metal is, of course, transferred out of the ladle by pouring. In most foundries multiple pours are needed to transfer the liquid metal from the melting unit to the mould.

At every pouring operation, it is likely that large areas of oxide film will be entrained in the melt because pour heights are usually not controlled. It is known that pour heights less than the height of the sessile drop cannot enthain the surface oxide. However, such heights are very low; 16 mm for Mg, 13 mm for Al, and only 8 mm for dense metals such as copper-base, and iron and steel alloys.

However, this theoretical limit, while absolutely safe, may be exceeded for some metals with minimum risk. As long ago as 1928 Beck described how liquid magnesium could be transferred from a ladle into a mould by arranging the pouring lip of the ladle to be as close as possible to the pouring cup of the mould, and relatively fixed in position. In this way the semi-rigid oxide tube that formed automatically around the jet remained unbroken, and so protected the falling stream.

Experiments by Din and Campbell (2002) on Al–7Si–0.4Mg alloy have demonstrated that in practice the damage caused by falls up to 100 mm appears controlled and reproducible. This is in close agreement with early observations by Turner (1965) who noted that air was taken into the melt, reappearing as bubbles on the surface when the pouring height exceeded about 90 mm.

Above 200 mm, Din and Campbell (2003) found that random damage was certain. At these high energies of the plunging jet, bubbles are entrained, with the consequence that bubble trails add to the total damage in terms of area of bifilms.

In general, it seems that the lower the pour height the less damage is suffered by the melt. In addition, of course, less metal is oxidized, thus directly saving the costs of unnecessary melt losses. Ultimately, however, it is, of course, best to avoid pouring altogether. In this way losses are reduced to a minimum and the melt is maintained free from damage.

Until recent years, such concepts have been regarded as pipe dreams. However, the development of the Cosworth Process has demonstrated that it is possible for aluminium alloy castings to be made without the melt suffering any pouring action at any point of the process. Once melted, the liquid metal travels along horizontal heated channels, retaining its constant level through the holding furnace, and finally to the pump, where it is pressurized to fill the mould in a counter-gravity mode. Such technology would also appear to be relatively easily applied to magnesium alloys.

The potential for extension of this technology to other alloy base systems such as copper-based or iron-based alloys is less clear. This is because many of these other alloy systems either do not suffer the same problems from bifilms, or do not have the production requirements of some of the high volume aluminium foundries. Thus in normal circumstances, many irons and steels are relatively free from bifilms because of the large density difference between the inclusions and the parent melt, encouraging rapid flotation. Alternatively, many copper-based and steel foundries are more like jobbing shops, where
the volume requirement does not justify a counter-gravity system, and high technology pumps, if they were available, would have problems surviving the oxidation and thermal shock of a stop-go production requirement.

Despite these reservations, the counter-gravity Griffin Process has been impressively successful for the volume production of steel wheels for rail rolling stock. The process produces wheels that require no machining (apart from the centre hub). The outer cast rim runs directly on the steel rail. The products outperform forged steel wheels in terms of reliability in service, earning the process 80 per cent of the market in the USA. What a demonstration of the soundness of the counter-gravity concept, contrasting dramatically with steel castings produced world-wide by gravity pouring, in which defects and expensive upgrading of the casting are the norm.

1.5 Melt treatments

1.5.1 Degassing

Gases dissolved in melts are disadvantageous because they precipitate in bifilms and cause them to unfurl, and even open further as cracks or voids, thereby progressively reducing the mechanical properties of the cast product.

Treatments to reduce the gas content of melts include vacuum degassing. Such a technique has only been widely adopted by the steel industry. If a melt were simply to be placed under vacuum the rate of degassing would be low because the dissolved gas would have to diffuse to the free surface to escape. The slow convection of the melt will gradually bring most of the volume near to the top surface, given time. The process is greatly speeded by the introduction of millions of small bubbles of inert gas via a porous plug or other technique. In this way the process is accomplished in a fraction of the time.

Traditionally the steel industry has used the technique of a carbon boil, in which the creation and floating out of carbon monoxide bubbles from the melt carries away unwanted gases such as oxygen (actively by chemical reaction with carbon) and hydrogen (passively by simple flushing action). The nitrogen in the melt may go up or down depending on its starting value and the nitrogen content of the environment above the melt, since it will tend to equilibrate with the environment. The more recent oxygen steelmaking processes in which oxygen is injected into the melt certainly reduce hydrogen and nitrogen, but require the oxygen to be reduced either chemically by reaction with C or other deoxidizers such as Si, Mn or Al etc., or use even more modern techniques such as AOD (argon-oxygen-decarburization). We shall not dwell further on these sophistications, since these specialized techniques, so well understood and well developed for steel, are almost unused elsewhere in the casting industry.

By comparison, the approaches to the degassing of aluminium alloys, containing only hydrogen, has for many years been primitive. Only recently have effective techniques been introduced.

For instance until approximately 1980, aluminium was commonly degassed using immersed tablets of hexachlorethane that thermally degraded in the melt to release large bubbles of chlorine and carbon (the latter as smoke). Alternatively, a primitive tube lance was used to introduce a gas such as nitrogen or argon. Again large bubbles of the gas were formed. These techniques involving the generation of large bubbles were so inefficient that little dissolved gas could be removed, but the creation of large areas of fresh melt to the atmosphere each time a bubble burst at the surface of the melt provided an excellent opportunity for the melt to equilibrate with the environment. Thus on a dry day the degassing effect might be acceptable. On a damp day, or when the flue gases from the gas-fired furnace were suffering poor extraction, the melt could gain hydrogen faster than it could lose it. This poor rate of degassing, combined with the high rate of regassing from interaction with the environment, led to variable and unsatisfactory results.

Rotary degassing came to the rescue. The use of a rapidly rotating rotor to chop bubbles of inert gas into fine clouds raised the rate of degassing and lowered the rate of regassing. Thus effective degassing could be reliably achieved in times that were acceptable in a production environment.

It is to be hoped that this is not the end of the story for the degassing of aluminium alloys. For instance the use of an 'inert' gas is a convenient untruth. Even sources of high purity inert gas contain sufficient oxygen as an impurity to create an oxide film on the inside of the surface of the bubbles. Thus millions of very thin bifilms must be created during this degassing process. For a new rotor, or after a weekend, the rotor and its shaft will have absorbed considerable quantities of water vapour (most refractories can commonly absorb water up to 10 per cent of their weight). Furthermore, the gas lines are usually not clean, or contain long rubber or plastic tubing. These materials absorb and therefore leak large quantities of volatiles into
the degassing line. Thus by the time the gas arrives in the melt it is usually not particularly inert. At this time no-one knows whether the oxides created as by-products of degassing are negligible or whether they seriously reduce properties. What is known is that aluminium alloys are usually greatly improved by rotary degassing. Whether further improvements can be secured is not clear.

Part of the considerable benefit of rotary degassing is not merely the degassing action. It seems that the millions of tiny bubbles attach to oxides in the melt and float them to the top, where they can be skimmed off. After treatment, after the rotor has been raised out of the melt and the surface skimmed, a test of the efficiency of the cleaning action is simply to look at the surface of the melt. If the cleaning action is not complete, during the next few minutes small particles will be seen to arrive at the surface, under the surface oxide film, which is seen to be pushed upwards by the particle. The treatment can be repeated until no further arrival of debris can be seen. The melt surface then retains its pristine mirror smoothness. The melt can then be pronounced as clean as the treatment can achieve.

The action of rotary degassing on oxide films merits further examination. Much has been written on the benefits of small bubbles on the rate of degassing (although the rate of regassing from a damp rotor, or from the environment has been neglected). The action of the bubbles to eliminate films has in general been overlooked. However, the size of bubbles in relation to the efficiency of removal of films is probably critical. For instance, large bubbles will displace large volumes of melt during their rise to the surface, thus displacing films sideways, so that the film and bubble never make contact. On the other hand, small bubbles will displace relatively little liquid, and so be able to impact on relatively large films in their path. Thus such contacted films will be buoyed up to the surface. The mutual contact would be expected to become important when bubbles and films were approximately similar in size. Thus small bubbles will take out correspondingly smaller oxide films. This predicted effect deserves to be demonstrated experimentally at some future date.

An experience by the author illustrates some of the misconceptions surrounding the dual role of hydrogen and oxide bifilms in aluminium melts. An operator used his rotary degasser for 5 minutes to degas 200 kg of Al alloy. The melt was tested with a reduced pressure test (RPT; see below) sample that was found to contain no bubbles. The melt was therefore deemed to be degassed. The melt was immediately poured into a transfer ladle on a fork lift truck and conveyed to a low-pressure die casting furnace, into which it was poured. The melt in the low-pressure furnace was then tested again by RPT, and the sample found to contain many bubbles. The operator was baffled. He could not understand how so much gas could have re-entered the melt in only the few minutes required for the transfer.

The truth is, of course, that the melt was insufficiently degassed with only 5 minutes of treatment. In fact with a damp rotor the gas level is likely to rise initially (getting worse before it gets better!). The RPT showed no bubbles not because the hydrogen was low, but because the short treatment had clearly been sufficiently successful to remove a large proportion of the bifilms that were the nuclei for the bubbles. This high hydrogen metal was then poured twice, each time from a considerable height, re-introducing copious quantities of oxide bifilms that act as excellent nuclei, so that the RPT could now reveal its high hydrogen content.

1.5.2 Additions

Additions to melts are made for a variety of reasons. These can include additives for chemical degassing (as the addition of Al to steel to fix oxygen and nitrogen) or grain refinement (as in the addition of titanium and/or boron or carbon to Al alloys). Sometimes it seems certain that the poor quality of such materials (perhaps melted poorly and cast turbulently, and so containing a high level of oxides) can contaminate the melt directly.

Indirectly, however, the person in charge of making the addition will normally be under instructions to stir the melt to ensure the dissolution of the addition and its distribution throughout the melt. Such stirring actions can disturb the sediment at the bottom of melts, efficiently re-introducing and re-distributing those inclusions that had spent much time in settling out. The author has vivid memories of wrecking the quality of early Cosworth melts in this way: the addition of grain refiners gave wonderfully grain refined castings, and should have improved feeding, and therefore the soundness of the castings. In fact, all the castings were scrapped because of a rash of severe microporosity, initiated almost certainly on the stirred-up oxides that constituted the sediment in the holding furnace.

Additions of Sr to aluminium melts have often been accused of also adding hydrogen because of the porosity that has often been
noted to follow such additions. Here again, it seems unlikely that sufficient hydrogen could be introduced by such a small addition. Perhaps the problem is with stirred sediment, or other more complex reasons as are discussed at some length in Castings 2003.

1.6 Filtration

Filtration is perhaps the most obvious way to remove suspended solids from liquid metals. However, it is not without its problems, as we shall see.

The action of a filter in the supply of liquid metal in the launder of a melt distribution system in a foundry or cast house (i.e. a foundry for continuous casting of long products) is rather different from its action in the running system of a shaped casting.

The filters used in castings act for only the few seconds or minutes that the casting is being poured. The velocities through them are high, usually several metres per second, compared to the more usual 0.1 m/s rates in launders. The filtration effect is further not helped by the concentration of flow through an area often a factor of up to 100 smaller than that used in launder systems. The total volume per second rates at which casting filters are used are therefore higher by a factor of around 1000. It is hardly surprising therefore that the filtration action is reduced nearly to zero. However, the effect on the flow is profound. The use of filters in running systems is dealt with in detail later in the book. We concentrate in this section on filters in launder systems.

The treatment of tonnage quantities of metal has been developed only for the aluminium casting industry. The central problem for most workers in this field is to understand how the filters work, since the filters commonly have pore sizes of around 1 mm, whereas, puzzlingly, they seem to be effective in removing a high percentage of inclusions of only 0.1 mm diameter. Most researchers expand at length, listing the mechanisms that might be successful to explain the trapping of such small solid particles. Unfortunately, these conjectures are probably not helpful, and are not repeated here.

The fact is that the important solids being filtered in aluminium alloys are not particles resembling small solid spheres, as has generally been assumed. The important particles are films (actually always double films that we have called bifilms). Once this is appreciated the filtration mechanism becomes much easier to understand. The films are often of size 1 to 10 mm, and so are, in principle, easily trapped by pores of 1 mm diameter. Such bifilms are not easily seen in their entirety in an optical microscope, the visible portions appearing to be much smaller, explaining why filters appear to arrest particles smaller than their pore diameters.

We need to take care. This explanation, while probably having some truth, may oversimplify the real situation. In Castings (2003), the life of the bifilm was described as starting as the folding in of a planar crack-like defect as a result of surface turbulence. However, internal turbulence wrapped the defect into a compact form, reducing its size by a factor of 10 or so. In this form it could pass through a filter, and finally open once again in the casting as the liquid metal finally came to rest, and bifilm opening (i.e. unfurling) processes started to come into action.

In more detail now, the trapping of compact forms of films is explained by their irregular and changing form. During the compacted stage of their life, they will be constantly in a state of flux, ravelling and unravelling as they travel along in the severely turbulent flow. Two-dimensional images of such defects seen on polished sections always show loose trailing fragments. Thus in their progress through the filter, one such end could become attached, possibly wrapping over a web or wall of filter material. The rest of the defect would then roll out, unravelling in the flow, and be flattened against the internal surfaces of the filter, where it would remain fixed in the tranquil boundary layer.

1.6.1 Packed beds

In practice, in DC (direct chill) continuous casting plants, filters have been used for many years, sited in the launder system between the melting furnaces and casting units. Commonly, the filtration system is a large and expensive installation, comprising a crucible furnace that contains a divided crucible. One half is filled with refractory material such as alumina balls, or tabular alumina. The flow of the melt down one half of the crucible, through a connecting port, and up through the deep packed bed of such systems has been shown to be effective in greatly reducing the inclusion count (the number of inclusions per unit area). However, it is known that the accidental disturbance of such filters releases large quantities of inclusions into the melt stream. This has also been reported when enthusiastic operators see the filter becoming blocked by the increasing upstream level of the melt, and stir the bed with iron rods to ease the flow of metal. It is not easy to imagine actions that could be more counter-productive.
Some work has been carried out on filtering liquid aluminium through packed beds of tabular or ball alumina (Mutharasan et al. 1981) and through bauxite, alumino-silicates, magnesia, chrome-magnesite, limestone, silicon carbide, carbon, and steel wool (Hedjazi et al. 1975). This latter piece of work demonstrated that all of the materials were effective in reducing macro-inclusions. This is perhaps to be expected as a simple sieve effect. However, only the alumino-silicates were really effective in removing any micro-inclusions and films, whereas the carbon and chrome-magnesite removed only a small percentage of films and appeared to actually increase the number of micro-inclusions. The authors suggest that the wettability of the inclusions and the filter material is essential for effective filtration.

An interesting application of a chemically active packed bed is that by Geskin et al. (1986), in which liquid copper is passed through charcoal to provide oxygen-free copper castings. It is certain, however, that the charcoal will have been difficult to dry thoroughly, so that the final casting may be somewhat high in hydrogen. Because of the low oxygen content it is likely that hydrogen pores will not be nucleated (as discussed in Castings (2003)). The hydrogen is expected therefore to stay in solution and remain harmless.

1.6.2 Alternative varieties of filters

Other large and expensive filtration systems include the use of a pack of porous tubes, sealed in a large heated box, through which the aluminium is forced. The pores in this case are of the order of 0.25 mm, with the result that the filter takes a high head of metal to prime it. However, the technique is not subject to failure because of disturbance, and guarantees high quality of liquid metal.

Other smaller and somewhat cheaper systems that have been used include a ceramic foam filter, usually designed to be housed in a box, sited permanently below the surface of the melt. The velocities through the filter are usually low, encouraged by the large area of the filter, usually at least 300 × 300 mm. The filter is only brought out into the air to be changed when the metal level either side of the filter box shows a large difference, indicating that the filter is becoming blocked.

The efficiency of many filtration devices can be understood when it is assumed that the important filtration action is the removal of films (not particles). Thus glass cloth is widely used to good effect in many different forms in the Al casting industry.

1.6.3 Practical aspects

It is typical of most filtration systems that the high quality of metal that they produce (often at considerable expense) is destroyed by thoughtless handling of the melt downstream.

Even the filter itself can give difficulties in this way. For instance if the melt exits the filter downwards, or even horizontally, causing fine jets of metal to form in the air, and plunge into the melt, additional oxide defects are necessarily created downstream. The avoidance of this problem is an important aspect of the designing of effective filters into the running systems of shaped castings, as will be discussed later.

Many have wondered whether the filter itself causes oxides because the flow necessarily emerges in a divided state, and therefore must create double films in the hundreds of confluence events. Video observations by the author on a stream of aluminium alloy emerging from a ceramic foam filter with a pore diameter close to 1 mm have helped to clarify the situation. It seems true that the flow emerges divided as separate jets. However, within a few millimetres (apparently depending on the flow rate of the metal) the separate jets merge. Thus the oxide tubes formed around the jets appear to be up to 10 mm long when the melt travelled at around 500 mm s⁻¹ but remained attached to the filter. The oxide tubes did not extend further because after the streams merged oxygen was necessarily excluded. The forest of tubes was seen to wave about in the flow like underwater grass. It is possible that more rapid flows might cause the grass to detach as a result of its greater length and the higher speed of the metal. This seems much more likely in the conditions of the running system of a casting.