Measuring the thermal efficiency of feeding aids

During recent years Foseco have made significant advances in the development of highly efficient feeding aids to ensure that foundry systems can be produced with optimum thermal efficiency, refractoriness and ecological performance for any size of riser, cast in any metal. Coupled with the development of new formulations, has been the philosophy to research and publish thermal data and experimental techniques that will enable the foundryman to calculate with certainty the minimum Foseco aided riser which ensures a sound casting and gives maximum metal utilisation.

This article outlines some of the techniques which Foseco have been, and still are, researching, to fulfill this requirement.

To undertake this research Foseco has extensive laboratory facilities including an experimental foundry (Figure 1) where steel test castings of up to 600 kg gross weight can be made to examine the thermal efficiencies of feeding aids on a practical basis under closely controlled experimental conditions.

The AMITEC* Instrument

The AMITEC equipment, developed by Foseco, is a device specifically designed to provide comparative performance of insulating and exothermic materials, including riser and ladle tapping compounds. It consists of an insulated electrical furnace with a silicon carbide test plate fitted to the upper surface to accept specimens in board or powder form. The plate is maintained at a constant temperature (generally 1420 ± 2°C) during the test.

Fig. 1: A view of part of the Foseco experimental foundry showing the HIP electric induction furnaces used for steel melting.

Fig. 2: Illustrating the relative insulating characteristics of some riser linings determined with the Foseco AMITEC equipment.

After correction for background losses the equipment gives an accurate measure of heat flow into and through the test material. The heat transfer graphs shown in Figure 2 indicate the initial chilling effect of the sample.

- quantify the nature and duration of any exothermic reaction.
- quantify the insulating properties of the sample.
- measure a measure of thermal conductivity under steady state conditions.

Although measurements are not in absolute values the instrument can be used as a comparator, giving information about the relative thermal efficiency of, or, as Maitt defines in Figure 3, an approximate measure for the extension of solidification time achievable from the use of exothermic insulating materials.
Like any hot plate test, the AMITEC equipment cannot fully simulate liquid metal contact conditions, and therefore does not take into account undesirable factors such as compression or reaction with molten steel. A further limitation also exists in that the operating temperature of the furnace corresponds to a plate surface temperature of 1420°C maximum, whereas in practice the material may be used in contact with steel at temperatures exceeding 1500°C. Nevertheless, these heat transfer graphs give a good indication of expected performance.

(b) Modulus Extension Factor – Solidification

It was Chvorić who first recognised the fact, later developed by Wlodawer, that the time taken for a casting or riser to solidify is proportional to the ratio of the volume to the surface area of the casting or riser.

\[ T = K \left( \frac{V}{A} \right) \]  

where \( T \) = solidification time; 
\( K \) = the solidification constant which is dependent on the metal being cast and the nature of the mould material in contact with the casting or riser; 
\( V \) = volume of casting or riser; 
\( A \) = cooling surface area of casting or riser.

The ratio \( \frac{V}{A} \) is commonly known as Modulus \( M_e \).
\[ T = KM_e^2 \]  

In steel risering practice it is generally accepted that if the modulus of the riser, \( M_r \), exceeds that of the casting, \( M_c \), by a factor of 1.2 satisfactory feeding conditions are obtained in all but the most exceptional cases.
\[ M_r = 1.2 M_c \]  

Since the loss of heat from an insulated riser is much slower than from a riser of the same size which is not insulated, it is obvious that the apparent modulus of the insulated riser is significantly greater than its geometric modulus.

The effect of riser insulation may therefore be represented with good accuracy in the modulus equation by introducing a factor, \( f \), known as the Modulus Extension Factor (MEF); this factor representing the extent by which the apparent modulus of an insulated riser exceeds its geometric modulus.
\[ M_r = f M_c \]  

\( f \) is 1.2 where \( M_r \) is the apparent modulus and \( M_c \) the geometric modulus of the riser.

Thus from equation (3) and (4) the geometric modulus of an insulated riser is related to the modulus of the casting by:
\[ M_r = 1.2 M_c \]  

Consequently the Modulus Extension Factor not only provides a quantitative means of evaluating the efficiency of a Feeding Aid; but also when the value of the MEF is known the proper size of an insulated riser can be calculated using equation (5).

Early investigators developed a method, subsequently improved by Wlodawer, for the determination of the Modulus Extension Factor which uses two identically sized spherical moulds. As is shown in Figure 4 one casting is lined with sand and the other with the material to be evaluated. The running system allows molten steel to be introduced simultaneously into both spherical mould cavities at an identical flow rate and temperature and a cooling curve from the steel in each sphere is plotted from Pt-Pt/Rh thermocouples located at the solidification centre. Figure 5 records some typical results obtained using Foseco Feeding Aids with carbon steel.

Because the spherical shape is difficult to manufacture with insulating or exothermic products, and whilst in any case this shape is seldom used in practice, Foseco have adapted this technique to other shapes such as for example cylindrical and domed risers. Whichever shape is employed however, the conditions for MEF determination by this technique are not strictly valid and the results may be misleading in practice. The method is limited by the fact that there is no feed demand on the specimen, because in neither test is the feeding aid superimposed on a casting. As a result, neither the volume nor the surface area of the metal in the sphere or cylinder changes other than to satisfy its own shrinkage demand.

(c) Modulus Extension Factor – Casting

Since it is apparent that the effect of volume changes in the casting on riser efficiency must also be allowed for, a more recent procedure has been to superimpose a cylindrical feeding aid sleeve on a test cube casting, and compare this with a larger sand lined riser, feeding a similar casting; that is to compare different types of feeder heads which solidify in the same time when feeding the same casting. The experimental procedure and resultant MEF for a riser lined with FEDEX 3 is shown in Figure 6.

This technique can yield very accurate results and has been employed extensively in recent years by Foseco to quantify MEF values for FEDEX, KALMIN, KALMINEX, KALBOR and KALBORD lined risers both in its own experimental foundry and also in practice, using production castings as shown in Figure 7. The method, however, still offers some minor disadvantages, one being that the expected final point of solidification in the riser must be accurately judged to ensure correct location of the thermocouple; in addition, it does possess...
the disadvantage that although it allows satisfactory assessment of side wall insulation it does not take proper account of the effect of the anti-piping compound used to cover the exposed surface of metal in open risers i.e. the MEF defines the combined effect of sidewall plus anti-piping compound. This deficiency has been remedied by Corbett, who points out that the influence of both side wall and anti-piping compound insulation can be accounted for separately by two factors termed "Apparent Surface Alteration Factor" (ASAF).

3. APPARENT SURFACE ALTERATION FACTOR

From the foregoing, it can be readily appreciated that the rate of heat loss through the side walls and from the top surface of an open sand lined riser, is significantly reduced by insulation.

Generally, however, the materials used to line the side wall and cover the top surface, are different, so that the rate of heat loss is not of the same magnitude.

For calculation purposes the ASAF of the insulation can be expressed by the ratio:

Rate of heat loss through the insulation / Rate of heat loss through the sand

For example, a material that allows a loss of heat at only half the rate of sand has an ASAF of 0.5.

A method to calculate the ASAF for a particular side wall insulator and/or APC can now be derived using the basic formula of Chvorinov given in equation (2).

For a fully insulated cylindrical riser with a non-cooling riser/casting contact face the modulus is given by:

\[
M' = \frac{\text{Volume}}{\text{Cooling Surface Area}} = \frac{\pi r^2 H}{2 \pi r H + \pi r y}
\]

where \(M'\) is Apparent Modulus of the cylindrical riser.

\(r\) = radius of riser.

\(H\) = height of riser.

\(x\) = ASAF of side wall insulation (for sand \(x = 1\)).

\(y\) = ASAF of anti-piping compound (for sand cover \(y = 1\)).

This can be reduced to:

\[
M' = \frac{4H}{4H + \pi y}
\]

and

\[
M'_i = \frac{4H}{4H + \pi y}
\]

where

\(D\) = riser diameter.

\(M'_i\) = ASAF of riser.

\(y\) = riser height/diameter ratio of 1:1; i.e. riser height = riser diameter.

Unlike the Modulus Extension Factor the ASAF decreases as the efficiency of the side wall lining or anti-piping compound increases.

No single value applies either to MEF or ASAF for any given insulating or exothermic material; the thermal efficiency factor of a feeding aid will vary depending on:

(a) the metal cast,

(b) the designs and dimensions of riser,

(c) the feed demand of various casting shapes, and

(d) the quality, formulation and applied thickness of the individual feeding aid.

However, the ASAF can be calculated for a Feeding Aid providing that the particular conditions for any given set of casting details

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Fig. 5: Modulus Extension Factor data derived from the Sphere Test.

Fig. 6: Procedure and results from Modulus Extension Factor trial.
(a) Determination of ASAFT

In the method outlined by Plutshack*, the ASAFT values are determined by measuring a material's effect on the geometric modulus of a riser under a fixed set of casting conditions. Using this technique, the apparent modulus of an insulated riser is determined by matching its feeding performance with that of a conventional sand head feeding the same casting. The apparent modulus of the sleeved head should be equal to the geometric modulus of a sand head which is necessary to obtain the same feed safety margin. This matching procedure is facilitated by casting a series of open sand lined heads topped with loose sand of progressively larger sizes feeding the same casting. A relationship between riser modulus and feed safety margin can then be obtained for the particular casting. Such a relationship for a sand riceoned steel test cube of 10 cm sides is shown in Figure 8.

(b) CASTING AFTER RISER REMOVAL

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\[ \frac{x}{y} = \frac{\text{ASAFT of lining (sleeve)}}{\text{ASAFT of topping (sand)}} \]

\[ y = 1.0 \]

ASAFT of a 7.5 cm ID x 7.5 cm high KALMIN 4170 (8 mm wall) is 0.622.

(c) ASAFT of Anti-Piping Compound

When the ASAFT of the sleeve material is known, the ASAFT of any topping material may be determined by making another casting using an identical KALMIN 4170 sleeve but replacing the loose sand topping with the material to be tested. The feed safety margin is measured and the apparent modulus of the riser determined from the graphs as before.

For example, line (c) in Figure 8 shows the result of using an anti-piping compound FERRUX 707F at an application thickness of 7.5 mm (D/10 where D = riser diameter). The feed on this casting is now +11 mm, and from Figure 8 this riser must have an apparent modulus of 2.55 cm. (See Figure 9c for sectioning casting result.)

The ASAFT of this 7.5 cm ID x 7.5 cm high sleeve (a) has already been found to be 0.622. Using equation (8), y is calculated as follows:

\[ y = \frac{D H}{4 H x + D y} \]

where M1, M2, D, H, x, and y are all known.

\[ y = 0.453 \]

ASAFT value for FERRUX 707F applied at a thickness of D/10 under these conditions is 0.453.

All ASAFT values quoted further in this report have been determined using this method, the only difference to the model shown in Figure 8 being the scaling up of the casting size and/or alterations to the casting design to accommodate the examination of ASAFT values for sleeves of larger internal diameter, and/or to examine the influence of more volumetrically controlled castings upon ASAFT values.

As Figure 10 serves to illustrate, it is an ill advised practice to select an anti-piping compound based solely on a low cost per unit weight basis.

The ASAFT model now quantifies very precisely and clearly that the hot topping is a critical component of a feeding system, and
1. If maximum cost effectiveness is to be achieved the hot topping must be of the highest quality, and it must be used in adequate quantity.

2. Figure 11 clearly demonstrates that FERRUX 707F, which is a high quality expandable material, is considerably more effective (lower ASAIF) than the low cost grades, or non proprietary materials such as Perlite or Rice Husks, even when these are applied at more than twice the thickness of the FERRUX 707F used in the test.

These latter non-proprietary materials suffer from thermal degradation resulting in extremely high ASAIF values, which can exceed 1.3, compared to the FERRUX 707F range of 0.42–0.78 over the same riser size range.

4. ADVANTAGES OF THE ASAIF MODEL

Although, the ASAIF technique may not be entirely ideal, of the techniques reviewed, (and which in recent years have been fully explored), the ASAIF model appears to apply in practice. Also, the technique allows research workers to examine the large number of factors which contribute to the improvement of existing feeding aids and the development and evaluation of entirely new materials. Intrinsic advantages of the ASAIF method over other techniques are:

1. The data is collated under practical yet strictly controlled conditions which reproduce casting production practice.

2. The method can clearly and decisively isolate, and quantify, the thermal efficiencies of both the side liner and the anti-piping compound.

3. The ASAIF data is precise because a true comparison is obtained when each of the heads, sand and insulatid, is performing the same functions with equal efficiency.

4. The quantified ASAIF data can be used directly by the steel foundry to calculate the required dimension of insulated riser, i.e. by substitution of the known x and y values into equation (9). No translation, conversion or alteration to the ASAIF value is required.

5. Although the details are outside the scope of this paper, the ASAIF model is not solely restricted to quantifying the effectiveness of riser insulation.

Research using a slightly refined model allows ASAIF values to be collated on insulators used in casting functions, as well as on chilling agents.

In common with all models that utilise steel pouring techniques, the ASAIF model is limited by scale. Facilities are available at the Foseco research centre for detailed examination of ASAIF on KALMIN/KALMINEX lined risers of up to and including 300 mm diameter. Above this range, data have to be compiled from production castings.

Based on the development work undertaken in our own experimental foundry the value of ASAIF have been determined for Foseco feeding aids manufactured around the world, and for most casting conditions. As shown in Figure 12 these values have been built into tables, nomograms and calculators issued from time to time by the Foseco Group and they are now being used as the basis of a micro-computer programme being developed to determine the optimum added riser size for steel castings.

5. CONCLUSIONS

It is well known that method of steel castings by guess work is very often unsatisfactory both in terms of soundness and yield. Through the development of the Modulus concept and other application techniques, the steel foundryman can now calculate with reasonable margins of risk dimensions to ensure a sound casting.

It is also clear that in order to achieve maximum efficiency, steel foundries require reliable feeding aids of consistently high technical quality whose thermal efficiencies can be quantified in terms which are meaningful for practical steel foundry applications.

Foseco is committed to an extensive programme of research and development which will ensure that these objectives will continue to be achieved.

REFERENCES

2 CHVORINOY, N. Giesserei 27 (1940).
6 PLUTSHACK, L. Unpublished work.

FEEDING AIDS

It is well known that feeding aids, both sleeves and anti-piping compounds, from whatever source, generally contain elements such as for example carbon and aluminium, which would be undesirable if absorbed in significant amounts by molten steel.

A very careful and thorough examination has shown that in most circumstances such contamination does not take place. However, in one or two isolated instances, particularly in the case of large feeder sleeves, a very thin ring of metal of different chemical analysis has been observed where a sleeve has been in direct contact with the steel casting.

Although harmless in most cases, this thin skin may be undesirable in certain critical applications, for example in the case of low carbon steel castings. For such applications it is recommended that a sleeve is not located in direct contact with the casting but separated from it by a thin sand layer or that a breather core covering the base of the sleeve is employed. If in doubt consult your local Foseco Company before using a feeder sleeve in direct contact with the casting.