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Advanced thermo-physical data for casting process simulation – the importance of accurate sleeve properties

This paper describes the relevant thermo-physical properties that characterize the materials used in feeding systems as well as their measurement. The sensitivity of casting process simulation results to these parameters is explored to illustrate the relative importance of each parameter. A joint effort to measure and validate the properties of a number of feeding system materials is described. The goal of these activities has been to generate the most accurate possible description of the performance of these materials in casting process simulation.

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1 Introduction and challenges

Today casting process simulation is a well established tool for the optimization of casting design and methoding. In fact, simulation tools have slowly evolved to become an integrated part of the entire casting production process, from casting design to adjusting production parameters. Improving casting design and quality continue to drive the need for increasingly complex simulation models and the constant refinement of result range and accuracy. Expanding the availability and the quality of property data for the materials used in the casting process is critical in assuring that simulation results can be used as serious quantitative predictive tools. Accurate data describing the performance of feeding and filtration systems are integral to this process [1 to 7].

The importance of accurate thermo-physical properties for the accuracy of casting process simulation is illustrated for a practical example of sand data in **Figure 1**. Because of the importance of the sand thermal properties on the solidification and cooling of the casting, an accurate description of these properties is required to predict the porosity observed in the real casting (the same is true for all materials used in modeling this casting) [8].

Typically, feeding and filtration system suppliers collect a significant amount of data as part of the quality control process to ensure consistent product quality. However, to obtain relevant and accurate thermo-physical data for feeding system products requires the investment of considerable additional effort. The determination of material properties for these products for use in casting process simulation requires the use of sophisticated laboratory equipment and trained laboratory personnel to produce quality results. Typically, these types of tests would need to be performed at qualified outside laboratories.

Generally, the same materials may be used to produce a broad range of feeding system product shapes and sizes, and accurate data is required to accurately represent the performance across these broad ranges. This is only possible if the real thermo-physical properties of the materials are measured and used in simulation. Since the conditions under which properties are measured in a lab may be vastly different from the conditions the material experiences in the foundry, it is essential that further experimental effort is expended in validating the properties that describe their performance in casting simulation.

This paper begins by briefly describing the relevant thermo-physical properties that characterize the materials used in feeding systems as well as their measurement. Then, the sensitivity of casting process simulation results to these parameters is explored to illustrate the relative importance of each parameter. Finally, a joint effort to measure and validate the properties of a number of feeding system materials is described. The goal of these activities has been to generate the most accurate possible description of the performance of these materials in casting process simulation.

1.1 Properties describing the thermal behavior of a sleeve

The important material characteristics for describing heat transport, heat storage and heat release for all of the materials in the casting system are density (ρ), specific heat capacity (c_p), thermal diffusivity (α) and thermal conductivity

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(λ), as illustrated in **Figure 2**. Exothermic sleeves additionally generate heat (ΔH_{exo}). These basic properties can be measured as functions of temperature in a laboratory using equipment which is calibrated to be as accurate as possible. The test methods employed follow ASTM guidelines.

1.1.1 Density ρ

As a material is heated, it expands and thus, the density (ρ, kgm^{-3}) decreases and contributes significantly to the change of thermal properties. Density change as a function of temperature for sleeve materials can be measured using a push rod dilatometer. A typical density curve as a function of temperature for a sleeve material is shown in **Figure 3**.

1.1.2 Specific heat c_p

The specific heat capacity (c_p, Jkg^{-1}K^{-1}) of a material clearly affects its thermal behavior. A differential scanning calorimeter (DSC) can be used to determine the specific heat of an unknown sample of a sleeve material by comparing the sample's thermal response to that of a standard known material under identical conditions. A typical specific heat curve as a function of temperature for a sleeve material is shown in **Figure 4**.

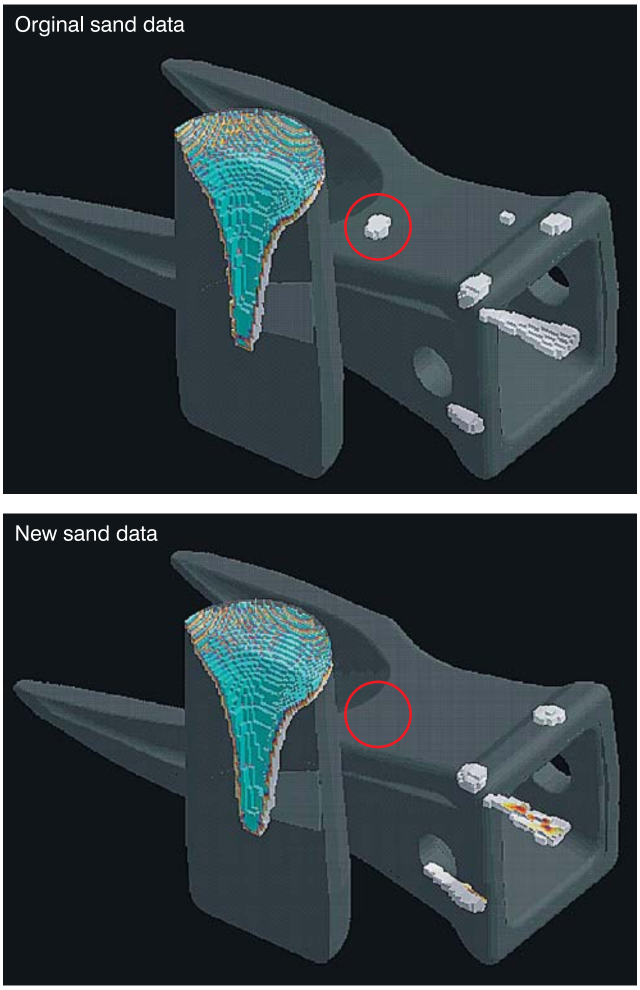


Figure 1: Dependent on the sand data, the circled porosity will or will not be predicted in the casting. Accurate data resulted in accurate defect prediction when compared to the real casting, as shown in the lower figure [8].

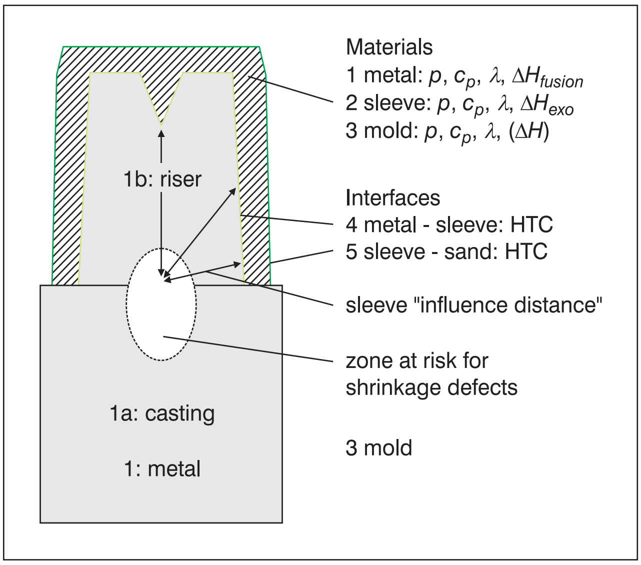


Figure 2: Basic geometry and parameters for the investigation of heat transport between casting, riser and sleeve, focusing on the validation of the basic sleeve material properties and heat transfer coefficients (HTC) at the sleeve interfaces

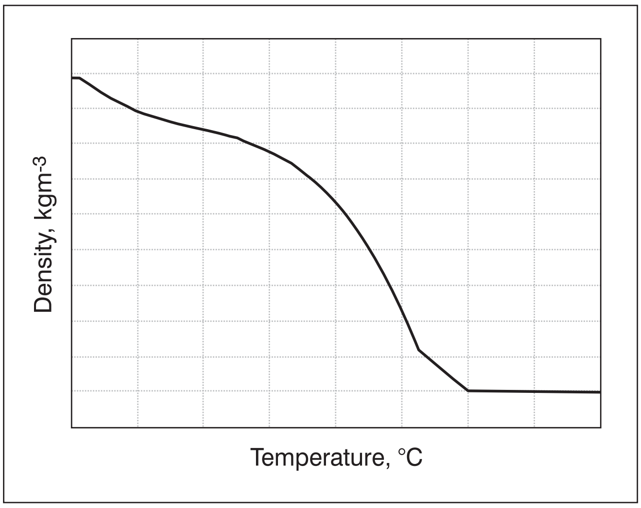


Figure 3: Typical measured density (ρ) curve as a function of temperature for a sleeve material

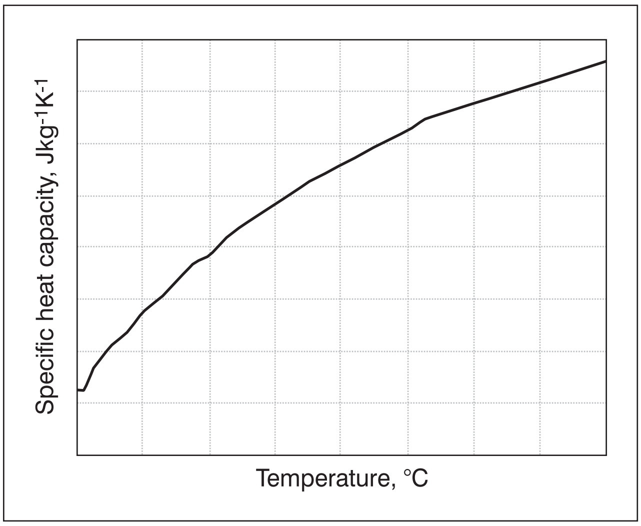


Figure 4: Typical measured specific heat (c_p) curve as a function of temperature for a sleeve material

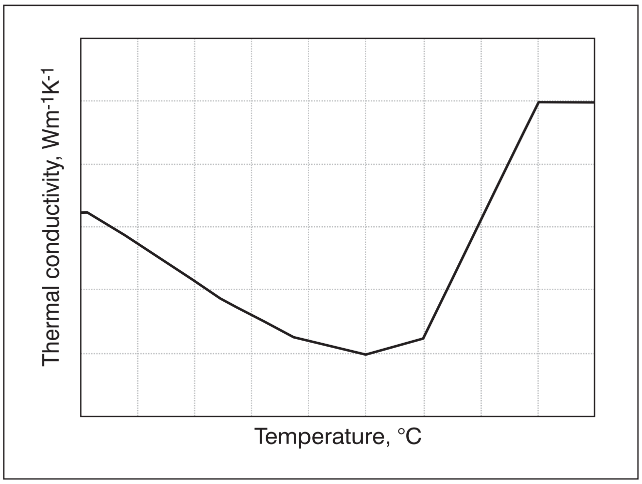


Figure 5: Typical measured thermal conductivity (λ) curve as a function of temperature for a sleeve material

1.1.3 Thermal diffusivity α

The thermal diffusivity (α, m^2s^{-1}) measures the ability of a material to conduct thermal energy relative to its ability to store it. Thermal diffusivity measurements for sleeve materials can be made using a laser flash device. A short duration laser impulse is directed toward and absorbed by one face of a flat slab specimen. The resulting heat propagates through the sample's thickness. The thermal response on the opposite face is monitored as a function of time, and the thermal diffusivity can be calculated.

1.1.4 Thermal conductivity λ

The thermal conductivity (λ, $Wm^{-1}K^{-1}$) of sleeve materials can be measured directly at lower temperatures on a guarded hot plate device. At higher temperature ranges of about 900 to 1600 °C, which are of typical interest in casting, the device is no longer accurate due to significant radiation heat losses. The thermal conductivity at higher temperatures has to be calculated from the measured density, specific heat and thermal diffusivity by the following equation:

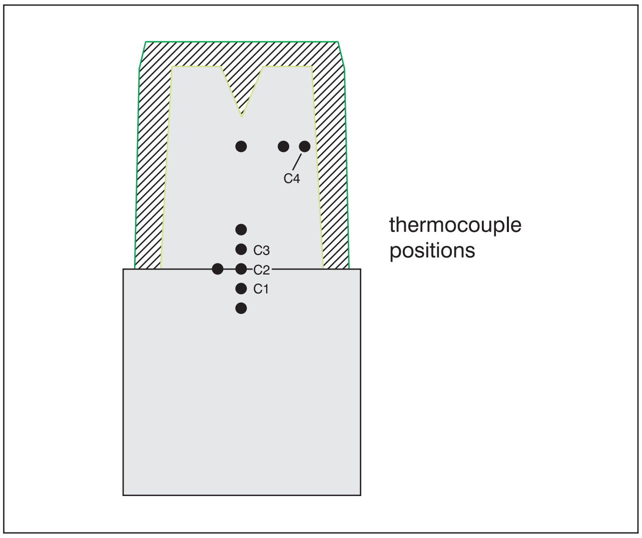


Figure 6: Test casting geometry and virtual thermocouple locations for the investigation of the sensitivity of basic sleeve parameters on the solidification behavior

$$\lambda = \rho c_p \alpha$$

A temperature dependent thermal conductivity curve for a sleeve material is shown in **Figure 5**.

1.1.5 Exothermic properties

The effectiveness of a riser sleeve is determined by how long the sleeve can delay the solidification of the metal within the riser. The heat released by an exothermic sleeve can slow and even prevent heat loss from the riser through the sleeve, thus retarding the formation of a solid shell in the early stages of casting solidification, as well as extending the total solidification time of the riser. In extreme cases such as spot feeding, the riser sleeve can be designed to provide a thermal mass capable of also re-heating the metal within the riser sleeve, which results in a significant increase in riser solidification time.

For this reason, knowledge about the heat generated by an exothermic sleeve is important for correctly modeling the solidification of the riser metal and how this metal feeds the casting. Clearly, the modeling of the complex reactions that lead to the exothermic heat release is beyond the scope of a casting process simulation. Rather, the heat release can be modeled using three parameters: the total exothermic energy generated per unit mass of sleeve material (ΔH_{exo}), the temperature above which the sleeve ignites and the exothermic reaction is initiated (ignition temperature, $t_{ignition}$), and the length of time that a small sample of sleeve material releases significant energy (burn time, t_{burn}).

1.1.6 Heat transfer coefficients (HTCs)

Whenever two materials are in contact, the temperature drop across the interface between them may be appreciable. The resistance to heat transfer across the interface is due primarily to surface roughness in combination with contact pressure. The thermal contact resistance between materials is typically modeled in casting process simulation by defining an interfacial heat transfer coefficient (HTC) between the materials. In the present case, the primary interfaces of interest are between the cast metal in the riser and the sleeve as well as between the sleeve and surrounding mold sand, as illustrated in Figure 2.

A heat transfer coefficient cannot be measured directly. Rather, they are inversely calculated based on experimentally measured temperature histories at different distances on both sides of the interface [9, 10]. Typical values for heat transfer coefficients between metal and sand range between 400 and 1000 $Wm^{-2}K^{-1}$.

2 Parameter sensitivities – thermo-physical data

As discussed above, an accurate description of the properties of all of the materials involved in the casting system is necessary if accurate simulation results are to be achieved. Variations in each of the properties in a thermo-physical dataset have a different degree of influence on the results of a casting simulation. A previous study thoroughly investigated the sensitivity of predicted solidification times for a steel casting to uncertainties in material property data for both the cast metal and the mold sand [11].

The results of that study showed that [11], for example, variations in the thermal conductivity of the sand had a more significant effect on the simulated solidification times 50 mm from the mold/metal interface than for similar variations in the density or specific heat capacity. A density or specific heat that was 50 % higher than the nominal values for that property led to a reduction in the predicted solidification time of 19 %. A sand thermal conductivity that was 50 % higher than the nominal property, on the other hand, led to a 28 % reduction in the predicted solidification time at the same location. Although these values cannot be generalized as they were obtained for a specific geometry and casting conditions, they do give some indication of the sensitivity of the simulation results to uncertainties in material properties. As sand surrounds the entire casting and dominates the volume in which the casting is solidifying, the sand properties have a significant influence on the predicted heat transfer and solidification behavior.

As the sleeve only surrounds the riser metal with a given thickness, it might be expected that the simulation results will show a somewhat lower sensitivity to the sleeve properties than to the sand properties. However, the properties of the sleeve clearly have a large local influence on the heat transfer, solidification and feeding in the riser and in the surrounding casting. To investigate these sensitivities, the sample test casting shown in **Figure 6** was chosen. The casting is a 14 cm GS52 cube with a ∅9.7 cm × 11.8 cm riser formed by a 1.5 cm thick insert sleeve cast in a furan sand mold. Virtual thermocouples were used to record local solidification times at the center of the feeder neck (C2), ±10 mm above and below the feeder neck (C1 and C3) and 5 mm from the sleeve/metal interface (C4). Simulations were carried out using nominal sleeve thermo-physical properties as well as with variations in the properties of ±50 %. Note that no release of exothermic energy by the sleeve was considered in the simulations described in this section.

Table 1 summarizes the sensitivity of the predicted local solidification times at the measured locations to the variations in the thermo-physical sleeve properties. As can be expected, the local solidification time in the riser close to the sleeve (C4) is most sensitive to variations in the sleeve properties. The solidification times near the center of the riser neck are also increasingly affected by the properties with increasing height in the riser. The results also show that the predicted solidification times are much more sensitive to inaccuracies in the thermal conductivity than to the density or specific heat. This seems to indicate that the heat transfer across the sleeve by conduction plays a more dominant role in the riser solidification than the rate of heating of the sleeve. For this reason, further analysis of the result sensitivity to the thermal conductivity has been carried out below.

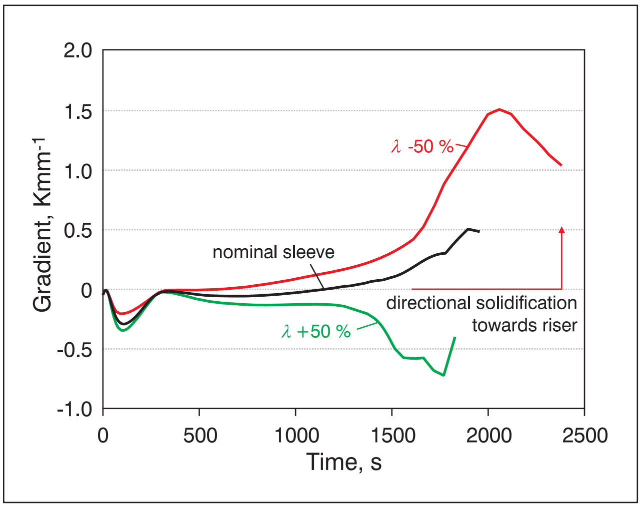


Figure 7: The effect of the sleeve's thermal conductivity on the vertical temperature gradient between the positions C2 and C1 at the riser neck (see Figure 6) during solidification. A positive gradient is necessary to ensure a directional solidification towards the riser, resulting in a defect free casting.

In order to gain a better understanding of the spatial sensitivity of the predicted temperatures and their effect on the feeding behavior of the riser, vertical gradients as a function of time were calculated between the positions C2 and C1. The results for variations in the sleeve thermal conductivity by ±50 % are summarized in **Figure 7**. A positive vertical temperature gradient during solidification indicates directional solidification toward the riser, which should result in a casting free of macro-porosity. The curves show that the changes in thermal conductivity changed the gradient significantly – by up to a factor of 3. This means that inaccuracies in the conductivity can be expected to lead to very different thermal conditions in the casting/riser system, leading to different predicted feeding behavior.

The gradient curves in Figure 7 indicate that porosity problems are likely to be predicted in the casting if the thermal conductivity is 50 % too large, whereas the casting should be predicted to be sound if the thermal conductivity is 50 % too small. This is confirmed by the results for the predicted feeding behavior shown in **Figure 8**. A variation of ±50 % for the thermal conductivity leads

Table 1: The solidification times near the riser neck (C1 to C3 in Figure 6) and within the riser at the interface to the sleeve (C4) demonstrate the sensitivity of casting simulation results to sleeve thermo-physical property variations. The solidification time for different parameter variations is compared to the nominal sleeve properties.

Sleeve properties	Riser neck solidification time, s						Sleeve interface	
	C1, s	±%	C2, s	±%	C3, s	±%	C4, s	±%
nominal	1920		1942		1951		1738	
λ: -50 %	2059	6.77	2135	9.05	2205	11.53	2333	25.48
λ: +50 %	1779	-7.94	1768	-9.83	1727	-12.97	1337	-30.03
ρ or c_p: -50 %	1951	1.57	1962	1.03	1977	1.30	1800	3.41
ρ or c_p: +50 %	1888	-1.69	1901	-2.16	1900	-2.69	1662	-4.61

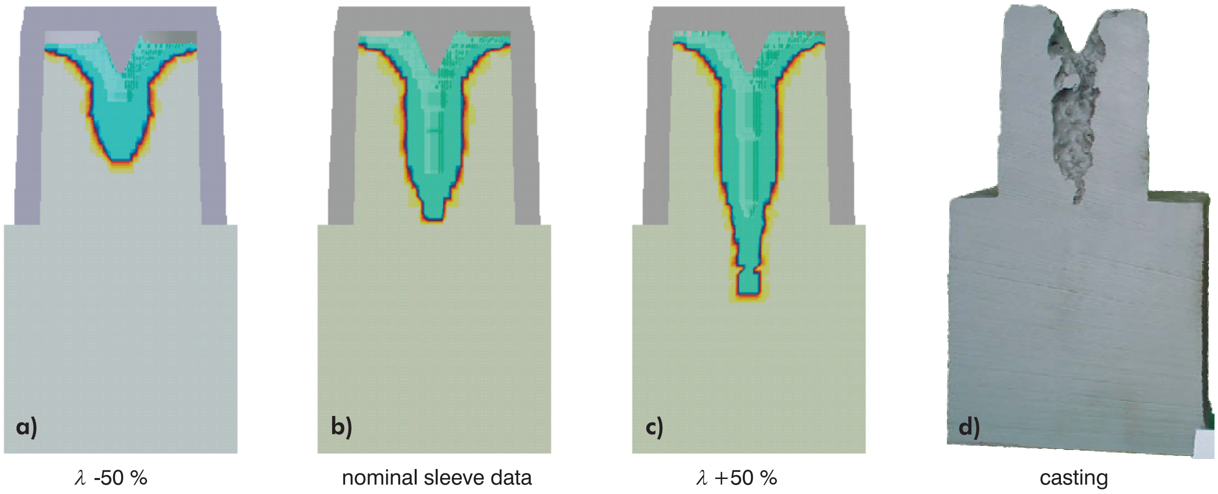


Figure 8: Sensitivity of predicted riser pipe and shrinkage to variations in the thermal conductivity of the sleeve

to significantly different piping depth predictions, especially in the case of tightly rigged castings such as the one selected here. The practical consequences of using inaccurate thermal conductivity data is that if a too low thermal conductivity is used (Figure 8a), the data is too optimistic and could lure the foundryman into using a riser size that might be inadequately small for the casting (as is the case here), thus causing scrap.

If the thermal conductivity is too large, the data is too conservative and could force the foundryman to use a larger riser than necessary, thus unnecessarily reducing foundry yield.

3 Parameter sensitivities – HTCs and exothermic properties

In addition to the thermo-physical properties investigated in the previous section, the sleeve exothermic energy as well as the heat transfer coefficients (HTCs) at the metal/sleeve and sleeve/sand interfaces are further important parameters for describing the heat transport and solidification in the riser and the casting it feeds. For both of these quantities there are no standard testing procedures that can be used for their measurement. Similar to the thermo-physical properties of sleeves, the sensitivity of simulation results to variations in these parameters has also been investigated. The same geometry type and conditions have been used as in the previous section. Because an exothermic sleeve will have a higher effective modulus than the purely insulating sleeve considered in the previous section, a slightly larger 16 cm cube with the same size riser was used here, resulting in a tightly rigged casting.

The sensitivity of solidification times at the riser neck and near the metal/sleeve interface to the chosen exothermic energy and HTC values is summarized in **Table 2**. The results show that in the riser neck (C1 to C3 in Figure 6) the solidification times are relatively insensitive to the ±50 % variations in the sleeve/metal and sleeve/sand HTC values – at least for the HTC values used here. This is due to the fact that the thermal conductivity of the sleeve plays a dominant role in the heat transfer across the sleeve. Near the sleeve/metal interface (C4 in Figure 6) the sensitivity of the solidification time to the HTC values is more significant. However, the sensitivity is still much smaller than for a similar percentage variation in the sleeve thermal conductivity. Comparing with Table 1, the sensitivity of the solidification times to a ±50 % variation in the exothermic energy is on the order of that of the sensitivity to the thermal conductivity. This indicates that the thermal conductivity and the

Table 2: The solidification times near the riser neck (C1 to C3 in Figure 6) and within the riser at the interface to the sleeve (C4) demonstrate the sensitivity of casting simulation results to variations in heat transfer coefficients and sleeve exothermic energy. The solidification time for different parameters is compared to the nominal sleeve properties.

Sleeve properties	Riser neck solidification time, s						Sleeve interface	
	C1, s	±%	C2, s	±%	C3, s	±%	C4, s	±%
nominal	2456		2484		2503		2152	
HTC: -50 %	2450	-0.24	2477	-0.28	2492	-0.44	2123	-1.35
HTC: +50 %	2468	0.49	2500	0.64	2525	0.88	2216	2.97
ΔH_{exo}: -50 %	2539	-4.32	2356	-5.2	2355	-5.91	1840	-14.50
ΔH_{exo}: +50 %	2406	3.38	2581	3.90	2615	4.47	2359	9.62

exothermic energy of sleeves are important parameters to accurately determine for accurate simulation results.

The variation in the simulated temperature gradient at the riser neck (C1 to C2 in Figure 6) with time is shown in **Figure 9** for the cases investigated. The same tendencies can be observed in the gradients as were seen in the solidification times in Table 2. The exothermic energy released by the sleeve plays a much more important role in the temperature field in the neck than the HTC values. Figure 9 also shows that the influence of the release of exothermic energy from the sleeve is primarily observed – at least at the riser neck – during the first portion of the solidification of the riser. At later times, the insulating behavior of the thermo-physical properties of the sleeve becomes the dominant influence on heat transfer in the riser. Note also, that although the same burn time was used for all of the simulations, the length of time the influence of the exothermic energy is visible at the riser neck depends on the amount of energy released by the sleeve. This is due to the thermal lag of the sleeve/ riser/sand system.

Finally, the predicted riser pipe and porosity for the nominal case is compared with the same predictions with variations in the exothermic energy in **Figure 10**. The figure shows, as one might expect, that the depth of the riser pipe and amount of secondary shrinkage decreases with increasing exothermic energy. As for the thermal conductivity, the consequence is that using inaccurate exothermic energy values in modeling the sleeve may lead to an under- or over-risering of the casting in practice.

4 Parameter sensitivities and property determination

The previous two sections have shown that varying different parameters describing the properties of sleeves can have similar consequences on the thermal and solidification behavior of a riser and the areas of the casting it feeds. This indicates that great care needs to be taken in determining these properties for their use in casting process simulation.

In order to further illustrate this point, the same example casting as in the previous section can be used. Here, three different cases have been investigated. The first is the same situation as the “nominal” case from the previous study of exothermic energy and HTCs, together with nominal sleeve/metal and sleeve/sand HTCs. In the second case, a much lower exothermic energy is used, together with correspondingly lower HTCs. In the final case, the same low exothermic energy has been used, but nominal HTC values are also used. In this last case, the sleeve thermal conductivity has also been reduced so that the total thermal resistance from the riser to the sand is approximately the same as for the case with low HTCs (a reduction in the thermal conductivity of 50 %).

The results of the comparison are summarized in **Table 3** and **Figure 11**. Comparing the solidification times in the neck in Table 3, it becomes quite clear that all three cases lead to very similar results. Note that a similar reduction in the thermal conductivity as in the last case led to a 7 to 11 % change in solidification times in Table 1. Here, the exothermic energy compensates for the reduction. On the other hand, the solidification times near the sleeve are much more significantly influenced by the chosen parameter vari-

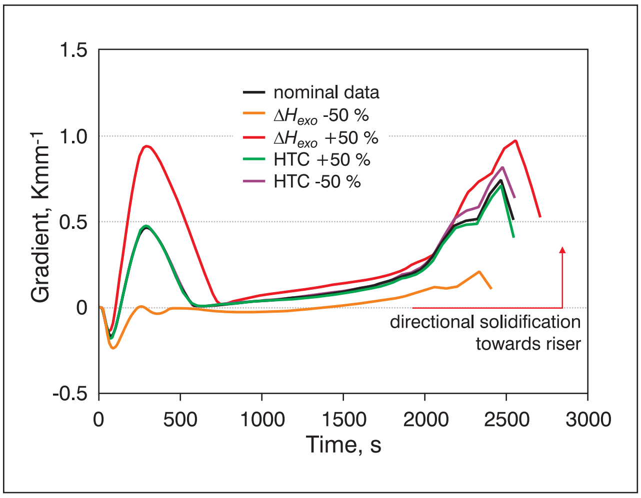
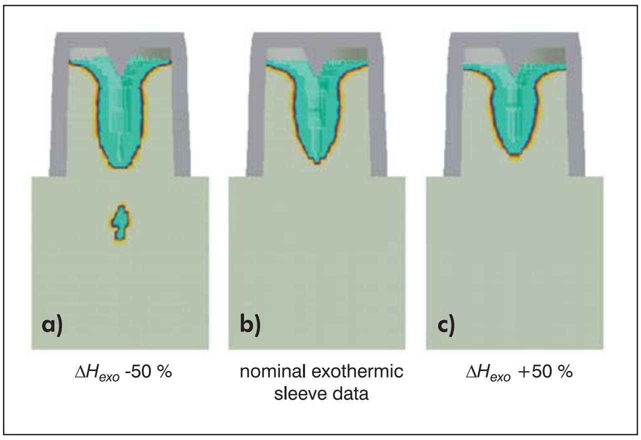


Figure 9: The effect of the sleeve's exothermic energy and sleeve/ sand and sleeve/metal HTCs on the vertical temperature gradient between the positions C2 and C1 at the riser neck (see Figure 6) during solidification. A positive gradient is necessary to ensure a directional solidification towards the riser, resulting in a defect free casting.



ΔH_{exo} -50 %

nominal exothermic sleeve data

ΔH_{exo} +50 %

Figure 10: Sensitivity of predicted riser pipe and shrinkage to variations in the exothermic energy of the sleeve

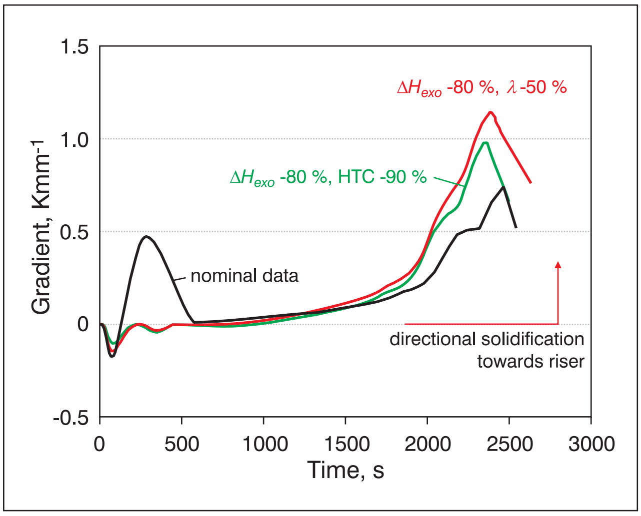


Figure 11: The effect of the sleeve's exothermic energy and sleeve/sand and sleeve/metal HTCs on the vertical temperature gradient between the positions C2 and C1 at the riser neck (see Figure 6) during solidification. A positive gradient is necessary to ensure a directional solidification towards the riser, resulting in a defect free casting.

Table 3: The solidification times near the riser neck (C1 to C3 in Figure 6) and within the riser at the interface to the sleeve (C4) demonstrate the sensitivity of casting simulation results to various sleeve parameter variations. The solidification time for different parameters is compared to the nominal sleeve properties.

Sleeve properties	Riser neck solidification time, s						Sleeve interface	
	C1, s	±%	C2, s	±%	C3, s	±%	C4, s	±%
nominal, sleeve data	2456		2484		2503		2152	
ΔH_{exo}: -80 % HTC: -90 %	2368	-3.58	2411	-2.94	2449	-2.16	2349	9.15
ΔH_{exo}: -80 % conductivity: -50 %	2406	-2.04	2462	-0.89	2517	0.56	2543	18.17

ations. The temperature gradients at the riser neck in Figure 11 also indicate a very similar history for all three cases. The only significant differences in the three curves are the period where exothermic energy is released and at later times when much of the riser is already completely solidified.

Based on the results in Table 3 and Figure 11, it could be expected that the predicted feeding behavior of the riser will also be similar for all three cases studied. The results in **Figure 12** show that this, in general, is true. In all three cases, the shape and depth of the riser pipe is comparable. For comparison, the predicted feeding behavior for a case where only the exothermic energy has been reduced is also shown. This comparison shows that either a reduction in the interfacial HTCs for the sleeve or a reduction in the sleeve thermal conductivity can compensate for a too low exothermic energy in the sleeve data.

These examples show that for a given experimental situation, these parameters can be chosen by trial and error until a satisfying result is achieved, giving the foundry engineer false confidence in the selected data. For example, a high exothermic energy can be compensated by increased heat transfer coefficients. Alternatively, a low exothermic energy can be compensated by defining unrealistically low heat transfer coefficients. Although a similar riser pipe depth for this specific case can be predicted, the overall heat balance of the system can be far from being realistic. For other casting configurations, the results are likely to be inaccurate and inconsistent. All of the parameter sensitivity results show that accurately measured properties and realistic heat transfer coefficients coupled with extensive validation for various casting configurations are absolutely required to perform realistic predictive simulations.

5 Validation of properties of exothermic sleeves

The previous sections have illustrated the importance of a thorough validation of any measured sleeve properties by comparison with experiments. The burning behavior of an exothermic sleeve may vary in detail as a function of temperature evolution and chemical composition of the atmosphere in a sand mold. For this reason, the properties of the sleeves need to be evaluated with real castings in the real burning atmosphere in the mold in the foundry. Due to the complicated sensitivities and interplay between the properties of the sleeve, it is necessary to run extended casting trials where temperature measurements are also made. It

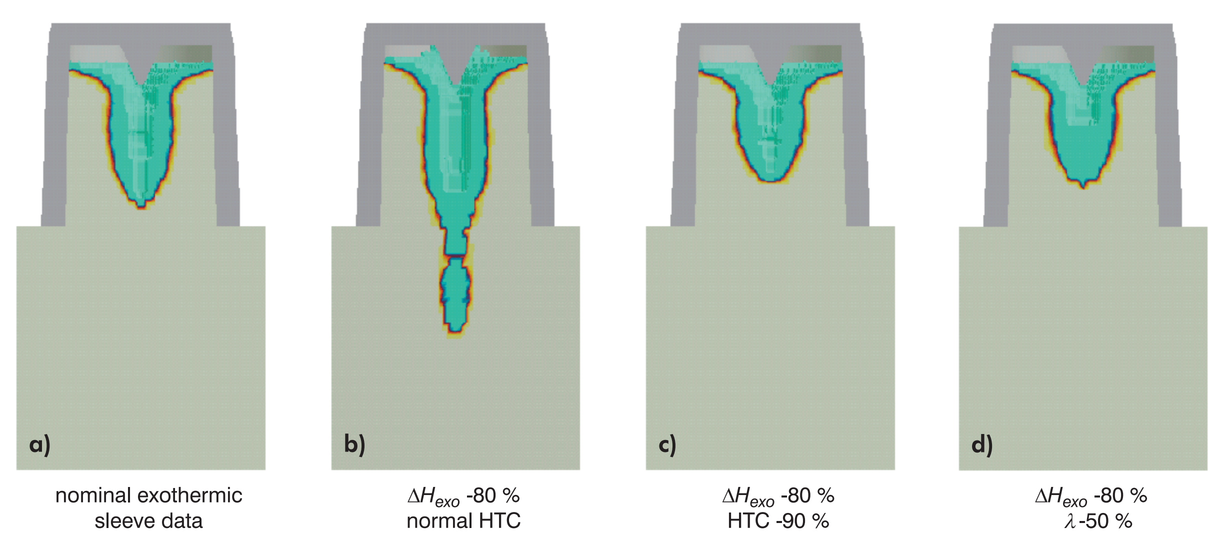


Figure 12: Simulation results for the investigation of the sensitivity of basic sleeve parameters on solidification and feeding behavior

then has to be proven that the material behavior is universally valid for a wide range of product sizes and casting conditions. This section describes the combined effort of Foseco and MAGMA to validate measured sleeve data taking all of these factors into consideration.

An experimental casting layout used as part of the validation is shown in **Figure 13**a. The castings consisted of 13.2 cm cubes fed by risers with insert sleeves. Both the mold and two of the castings on each pattern were instrumented with thermocouples as illustrated in Figure 13b. It was considered important to instrument more than one casting per mold to guarantee measured temperatures even if some of the thermocouples should fail and, just as importantly, to provide an estimate of the experimental uncertainty associated with the measurements. The thermocouples in the mold were placed at distances of 5, 10 and 15 mm from the casting or sleeve surface. The thermocouples in the castings were placed 10 mm from the top and bottom of the cube along the centerline as well as at the cube center. These thermocouples were protected by a ceramic tube. The GJS500 ductile iron castings were poured in a furan sand mold, with a pouring temperature of between 1345 to 1365 °C and a pouring time of approximately 18 seconds.

Castings were poured using Foseco FEEDEX, KALMINEX 2000, KALMINEX X and KALMIN S sleeves, with two different sizes of FEEDEX sleeves investigated. The thermal properties density, specific heat, and thermal conductivity had been measured for all of the sleeve materials as a function of temperature using the methods described above. Therefore, the emphasis in the comparisons between measured and simulated cooling curves was placed primarily on the exothermic properties. A numerical parameter study was carried out for each of the experiments by simulating various combinations of exothermic energy, burn time and ignition temperature for the sleeve material. Approximate values for each of these parameters obtained from previous experimental measurements were used as a starting point for the parameter studies. Although the cooling curves for each of the measured locations were compared, special attention was placed on the comparison of temperatures for the thermocouple at the top of the cube under the riser. This was due to the fact that this location is of critical importance for feeding of the casting and the performance of the riser.

The results of the parameter study showed that the exothermic energy and the burn time had the most influence on the simulated cooling curves. If the ignition temperature was limited to physically realistic values, it had a much lesser effect on the simulated results. By comparing the simulated cooling curves, including the simulated solidification times in the metal indicated by a knee in the curve, with the corresponding measurements, appropriate values for the exothermic energy and burn time could be determined for each product. **Figure 14** shows a comparison of measured and simulated temperatures at the top of the cube after adjustment of the properties.

Based on this combination of property measurement and experimental validation, a preliminary set of data for the thermo-physical and exothermic properties of the sleeve materials was available. To validate that this data adequately describe the sleeve in a variety of situations, the predicted feeding behavior of a wide range of sleeve sizes was compared with the observed riser piping and secondary shrinkage in both cast iron and steel test castings.

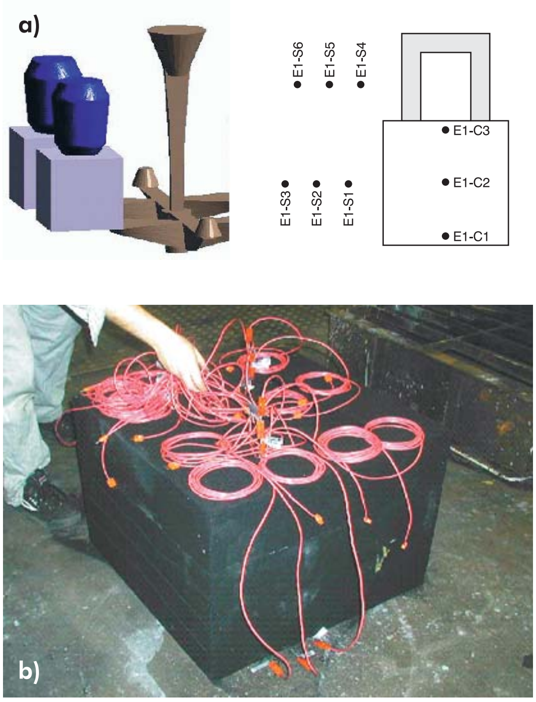


Figure 13: Casting lay-out and thermocouple positions (a) and instrumented mold (b) for sleeve data validation

Figure 15 shows an excerpt from these comparisons for both iron and steel castings with plate, cube and block geometries, with different sizes and types of sleeve products. The agreement between the simulated and observed riser pipe depth and shrinkage under the riser was in good agreement in nearly all of the cases investigated.

The product data sheets for the products used list effective modulus values (based on experimentally determined modulus extension factors). A MAGMASOFT® simulation also yields an effective thermal modulus distribution for the casting and riser in the form of the FEEDMOD result. As a final check, the simulated maximum FEEDMOD value in the riser was also compared with the effective modulus to ensure that these values were consistent. An example of these comparisons for a number of products is shown in **Figure 16**.

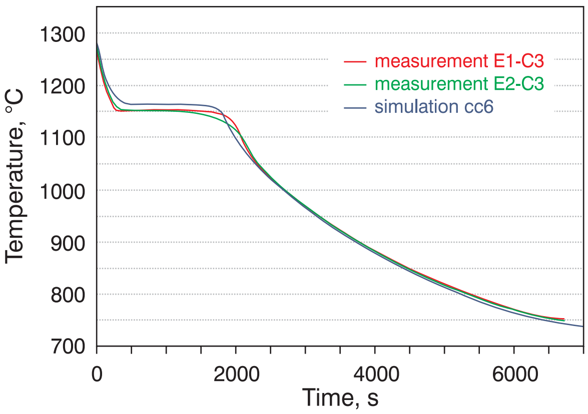


Figure 14: Comparison of measured and simulated cooling curves at the top of the test casting with an exothermic sleeve (see Figure 13a) after adjustment of the sleeve properties

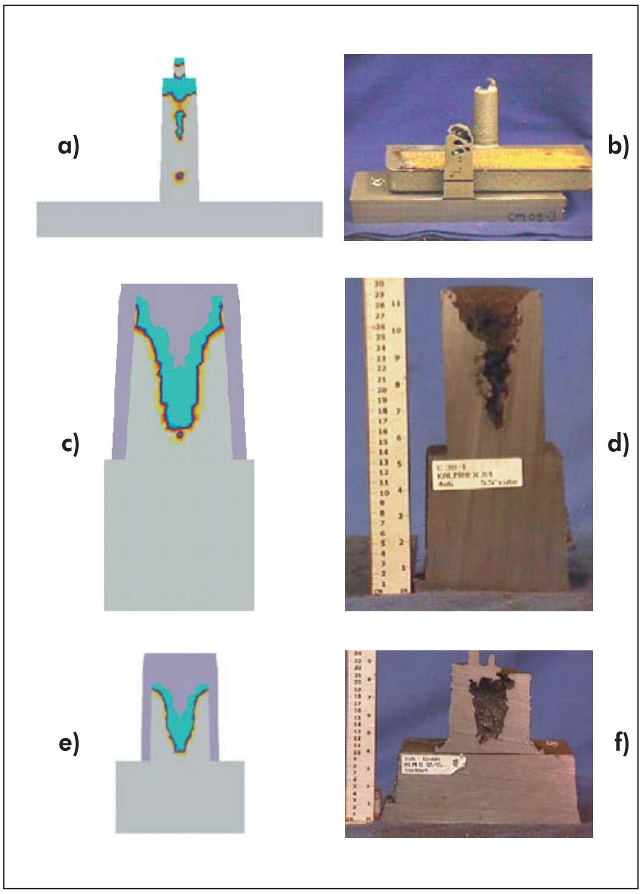


Figure 15: Comparison of riser pipe and casting soundness between simulation results (a, c, e) and experiment (b, d, f): a) and b) 29 × 29 × 3.6 cm GJS-500 ductile iron plate casting in a green sand mold with a FEEDEX V121 sleeve; c) and d) 14 cm cube C19Mn5 steel casting in a furan mold with a KALMINEX X 6 sleeve; e) and f) 25 × 25 × 10 cm C19Mn5 steel cube casting in a furan mold with a KALMIN S KSP 12/15K sleeve

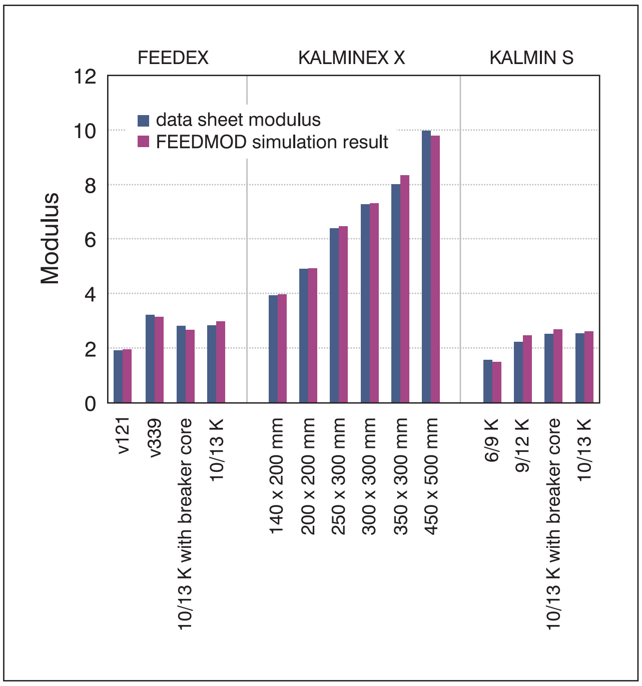


Figure 16: Comparison of the data sheet modulus values and simulated FEEDMOD results for a number of sleeve materials and sizes. The results show that the predicted and the actual performance of the sleeve products is the same.

In addition to the work presented here, further extensive validation trials have been performed to verify the validity of the properties of the sleeve materials used [4, 5]. At present, the validated data are being made available by Foseco and used with success on an industrial basis in a number of foundries as part of the Foseco Pro Module described in the following section. **Figure 17** shows a comparison of predicted and observed porosity in a ductile iron casting where the validated data has been used.

6 Sleeve data and the Foseco Pro Module

The Foseco Pro Module is a parametric 3D library of FOSECO sleeve and filter products, combined with a validated database of their characteristic thermo-physical properties. The module has been fully integrated into the MAGMASOFT® casting process simulation software.

Focusing on sleeves, the parameterized geometries can easily be selected with regard to cast alloy, size or modulus. Once chosen, the appropriate material data is automatically assigned to the geometry. As described above, this data has been thoroughly validated.

Also available are heat transfer coefficient data specific to Foseco feeding systems products and all relevant cast alloy groups. These data can be used to accurately describe the heat transfer between metal and sleeve, and between sleeve and mold.

The pressure drop data used to describe the properties of filters in the Foseco Pro Module was developed specifically for Foseco filtration products [6, 7]. MAGMASOFT® fluid flow predictions have been compared to x-rays of actual castings during filling, showing good agreement between predictions and reality. As for sleeves, the parameterized filter geometry can be selected from the database, and the appropriate pressure drop data are automatically assigned to the geometry.

The Foseco Pro Module has been designed to accurately define the critical performance metrics specific to Foseco feeding and filtration system products. Use of MAGMASOFT® and the Foseco Pro Module will ensure that the foundry is accurately and confidently modeling the performance of specific Foseco products.

7 Conclusions and outlook

The thermo-physical and exothermic properties of sleeves for use in casting process simulation have been investigated. A sensitivity analysis reveals that the primary factors influencing the predicted heat transport and solidification behavior of the riser are the thermal conductivity and exothermic energy released by the sleeve. The other thermo-physical properties density and specific heat capacity, as well as the heat transfer coefficients chosen for the sleeve/metal and sleeve/sand interfaces, have a much smaller influence on the solidification and feeding behavior. The sensitivity study shows that it is possible to reach locally similar predicted solidification times and feeding behavior of the riser by varying two of the parameters heat transfer coefficient/exothermic energy or thermal conductivity/exothermic energy. This illustrates the care that needs to be taken when trying to determine the properties of sleeves.

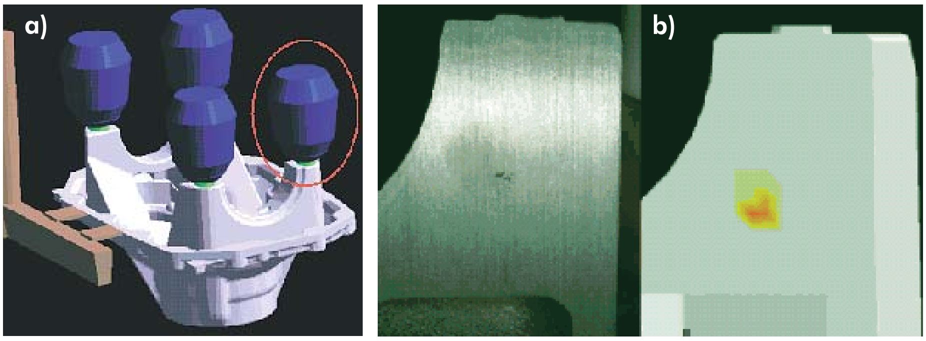


Figure 17: The correct prediction of porosity is a substantial validation criterion for a sleeve dataset, as proven with a complex ductile iron casting; casting lay-out (a) and validation of defect prediction (b).

Here, the methodology used to determine and validate the thermo-physical and exothermic properties of a number of Foseco sleeves has been described. The methodology is a combination of the measurement of thermo-physical properties in a laboratory as well as determination and validation of these properties through comparison of simulated and predicted temperatures and feeding behavior in test castings. The data is further validated by comparison of predicted and simulated riser pipes and secondary shrinkage for a wide range of sleeve sizes, cast materials and casting conditions. The resulting data are available as part of the Foseco Pro Module and show a good agreement between the predicted and observed feeding behavior of these products when used to simulate production casting processes.

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