Matching Your Crucible to Your Application

By Didier Finck and Dieter Heumannskaemper

Morgan Molten Metal Systems (UK, Germany)

If you melt metal or hold a molten bath, chances are your operation is unique. Your particular combination of furnaces, alloys, working practices, metallurgical treatments, pouring arrangements and end products are not likely to be duplicated at any other facility. So choosing a crucible that will provide maximum performance for your operation is an individualized and complex task.

This article is designed to serve as a guide for selecting the optimal crucible for your operation. It explains the relationship between metal melting/holding operations and specific crucible characteristics. It provides support for but does not replace the need for metal melters and crucible suppliers to work closely together in the crucible selection process.

The modern crucible is a highly heterogeneous, graphite-based composite material, which relies on its material composition and control of the graphite's structural alignment to achieve the performance required. Crucibles may be as small as teacups or may hold several tons of metal. They may be fixed in place within a furnace structure or may be designed to be removed from the furnace for pouring at the end of each melt. Crucibles are used in fuel–fired furnaces, in electric resistance furnaces, in induction furnaces or simply to transfer molten metal. They come with or without pouring spouts and in a wide variety of traditional and specialized shapes.

Fig. 1 Crucibles are available in a wide range of sizes and shapes and offer many different performance characteristics.

They also offer many different performance characteristics since each application presents a complex set of temperature, chemical and physical parameters which define the technical boundaries within which the crucible has to be designed to operate.

So how do you select the right crucible for your operation from the extensive range of crucible types and materials available to you?

The best approach is to begin with your own detailed assessment of your operations. You need to fully document and, where possible, quantify all aspects of your melting, holding and metal handling processes. These include:

- The capacity, dimensions and type of your furnace
- The specific alloy or range of alloys you melt
- The melting and/or holding temperatures you maintain
- The temperature change rate the crucible will experience
- How the crucible is charged
- The fluxes or additions used
- Degassing or refining processes
- How slag or dross is removed
- How the crucible is emptied.

These nine categories reflect the more common factors you must take into account when selecting a crucible to match your specific requirements. You also should consider any additional processes or requirements that might be specific to your operations. An example might be your ability to tolerate or your need to avoid alloy cross-contamination.

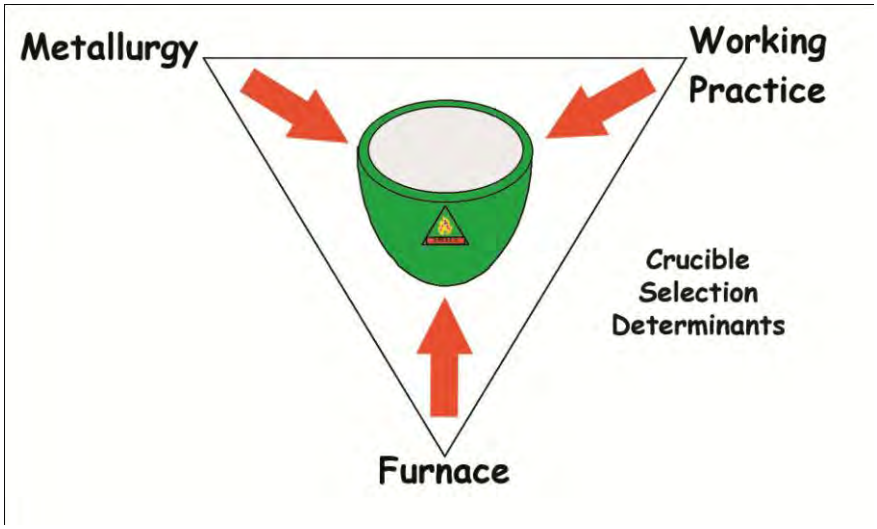

Fig. 2. Multiple considerations must be taken into account in selecting the right crucible for a specific application.

While you bring the detailed information on your own operations to the crucible selection process, your crucible supplier must contribute a high level of expertise on crucible materials, characteristics and performance. For the greatest selection, look for a

crucible supplier able to offer overlapping crucible product lines suitable for each specific metal but offering different operational characteristics. Then, working together, you will be able to closely match a specific crucible to your specific requirements. Achieving this match is the key to crucible safety, performance and maximum service life.

Be aware, however, that on a practical level, there may not be a single crucible type that offers the highest level of every desirable characteristic for your application. Crucible performance characteristics often involve trade-offs. For example, the crucible with the best thermal conductivity may not also offer the best protection against thermal shock. Therefore, you should prioritize the list of crucible properties most important for your application and review those priorities with your crucible supplier.

Furnace Capacity, Dimensions and Type

The capacity, dimensions and type of furnace you use will establish most of the observable details about your crucible. For example, when you know the metal capacity your furnace was designed for, you will know what capacity your crucible should provide. Similarly, the dimensions of the space for the crucible in your furnace will dictate the dimensions and shape of your crucible. This also will determine if your crucible must include a pouring spout. But choosing a crucible to match your furnace type will give you many other less obvious factors to consider.

Fuel-fired furnaces

Fuel-fired furnaces include furnaces powered by gas, oil, propane or coke. Each of these fuels directly exposes the crucible to the heating source and each provides a different level of heat, normally measured in BTUs. Any crucible selected must be able to withstand the maximum BTUs the furnace fuel is able to apply to the crucible. In gas, oil and propane furnaces, the crucible must be able to withstand the effects of the burner flame at the base of the crucible and the crucible must be tapered to allow the flame to circulate around the crucible from bottom to top. This allows even heating of the crucible. The crucible material also must be able to resist oxidation damage from the flame and accommodate the rate of thermal change the crucible will experience.

Good thermal conductivity and even heating are important crucible properties in transferring the heat from the interior of the furnace through the crucible to the metal charge. Crucibles with high graphite content in the carbon binder offer high thermal conductivity for fast melting in gas-fired furnaces.

Electric resistance furnaces

Electric resistance furnaces provide even, all-around heating to a crucible and are ideally suited to precise temperature control in metal holding application. But they are slower than fuel-fired furnaces in melting applications. Consequently, energy efficient crucibles with high graphite content in the carbon binder are often selected to provide high thermal conductivity for faster melting in these furnaces.

Crucibles designed for electric resistance furnaces are normally basin shaped and provide a uniform distance between the crucible and the furnace heating elements.

Induction furnaces

Selecting crucibles for induction furnaces is a more complex task. In some applications, such as refining precious metals, crucibles designed to heat in the furnace's inductive fields are used to melt the charge. In other applications, crucibles that allow the inductive field to pass through them and heat the metal charge directly are used. Therefore, it is important to match the electrical characteristics of the crucible to the operating frequency of the furnace and to the melting application. For example, in some designs, lower frequency induction furnaces require crucibles with high silicon carbide content and in other applications, higher frequency induction furnaces require crucibles with high clay content. Matching a crucible's electrical resistivity to the induction furnace is key to preventing crucible overheating.

Fig. 3. A cylindrical crucible is installed in an induction furnace.

Most crucibles designed for induction furnaces are cylindrical to provide a uniform distance between the crucible and the furnace coil. However, some small furnaces designed for removable crucibles feature a tapered coil to match the profile of bilge-shaped crucibles.

Removable crucible furnaces

All of the above furnace types can be designed to use removable crucibles. These crucibles can be charged while outside or when installed in the furnace, but they are removed from the furnace for pouring. Like crucibles used only for metal transfer, they are bilge-shaped or A-shaped to allow them to be lifted with tongs designed to properly support the crucible.

Furnace power limitations

A final factor to consider when documenting your crucible requirements based on your furnace's specifications is power availability. In many locations, power for melting or holding might not be available at all times or might be prohibitively expensive at certain

times or at certain levels. If this is the case at your facility, it may be particularly important to select an energy efficient crucible.

Metals You Melt and/or Hold

Knowing what metals and alloys you melt or hold will tell you a lot about what characteristics you need in a crucible. Your detailed catalogue of the metals you intend to melt will help to establish the maximum temperature the crucible must support for melting and holding, will define how the metal will interact with the crucible material both chemically and physically and it will be a key factor in determining what characteristics your optimal crucible should offer. A case in point, in melting copper-based alloys in fuel-fired furnaces, roller formed silicon carbide crucibles perform better due to higher thermal shock resistance. In other types of furnaces, crucibles are often selected because of their high density. Less dense and more porous crucibles may allow erosion.

Carbon-bonded and ceramic-bonded clay graphite and silicon carbide crucibles are widely use in melting and holding aluminum and aluminum alloys, aluminum-bronze, copper and copper-based alloys, cupro-nickel and nickel-bronze alloys, precious metals, zinc and zinc oxide. Crucibles also are used in melting cast iron. Taken together as a group, these metals represent a temperature range from 400°C/750°F to 1600°C/2912°F.

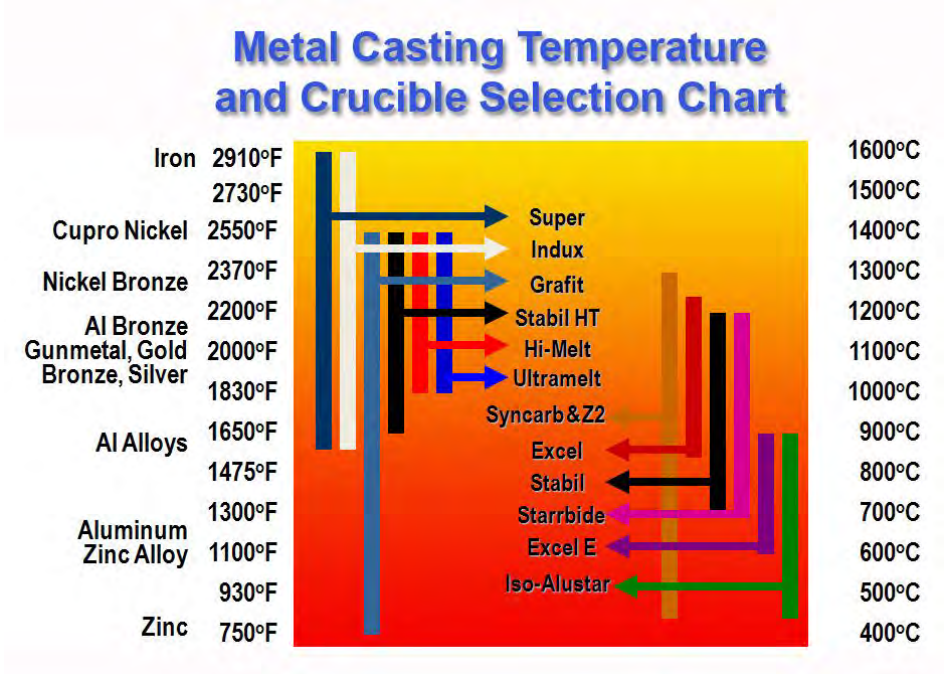

Fig. 4. A crucible must first support the range of metal temperatures it will encounter. But by offering products with overlapping temperature ranges, a crucible manufacturer is also able to provide a choice of crucibles with varying performance characteristics.

While some crucible types support metal temperatures encompassing a broad spectrum of metals, it often is necessary to select crucibles targeted to specific metals or alloys

and with more limited operating temperature ranges. Selecting such crucibles is often more advantageous because they offer performance characteristics important to your operations. For example, using a crucible able to melt metals from iron to zinc may not be as important to your aluminum alloy melting operation as having a crucible limited to the temperature range you need but able to resist corrosion damage from your metal treatment fluxes.

Melting and Holding Temperatures

Generally speaking, the metals and alloys you melt or hold will determine the temperature range within which your crucible must be able to operate. Crucibles must never be heated above their maximum temperature. This can lead to dangerous crucible failure. However, operating below the crucible's lower temperature limit can also cause problems. For example, crucibles designed for the high temperature melting of copper-based alloys will oxidize if used at low temperatures for zinc melting.

Melting and holding practices involving metal temperatures also need to be taken into consideration in selecting crucibles. If your operations involve superheating, you will need to take the higher metal temperatures reached into account.

Rate of Temperature Change

The ability of a crucible to handle the rate of temperature change is as important as its minimum and maximum temperature limits. If your operational practices lead to frequent heating and cooling cycles for the crucible or otherwise subject it to rapid temperature changes, you will need to select a crucible that is resistant to thermal shock. Some crucible types are much better at handling rapid temperature change than others. For example, high carbon content of the graphite in a crucible imparts high thermal conductivity and non-wetability. And when that graphite forms a directionally oriented matrix, the crucible also provides high thermal shock resistance. This is critical to foundry applications where temperatures can change by several hundred degrees in seconds**.** Your crucible supplier can advise which crucibles provide the best resistance to thermal shock for your application.

How the Crucible Is Charged

If your furnace is always charged with molten metal, it probably does not need a crucible designed to be highly resistant to physical damage. However, if metal ingots or other heavy materials make up the bulk of your charge and they are not carefully lowered into the furnace via an automatic loading system, you may want to select a crucible that is mechanically strong and able to survive physical shocks. Crucibles featuring high carbon content and a directionally oriented graphite structure provide excellent impact resistance**.**

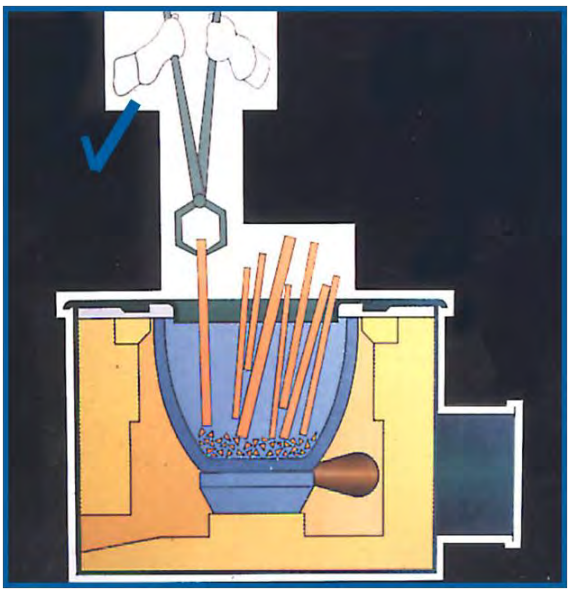

Fig. 5. Crucibles that provide impact resistance are often selected for furnaces that are manually charged with ingots and other solid materials.

You also will want a crucible with a durable protective glaze. Damage to the glaze from rough handling can lead to oxidation damage to the crucible. Extruded aluminum ingots often have sharp edges that cut deeply into a crucible's body leading to damaging cracks.

Fluxes and Additives

All crucibles offer some level of resistance to corrosion and chemical attack. But most fluxes and other metal treatments used in melting aluminum and other nonferrous metals are highly corrosive and require a crucible that offers a high level of resistance to chemical attack. This resistance is best imparted by both a consistently dense crucible material structure and a durable protective glaze. If your melting application involves the use of corrosive metal treatments, you certainly will want a crucible offering the appropriate level of protection against these agents.

Degassing and Refining

Degassing aluminum and aluminum alloys typically involves bubbling inert gas, usually nitrogen, through the molten bath while agitating the bath with a rotor designed to break apart and disperse the gas bubbles. These small bubbles then pull the undesirable hydrogen and oxides out of the bath and carry it, along with dross and inclusions to the surface where the gas escapes into the air and the solid material can be removed. This process, often used along with fluxing agents, physically erodes the crucible and attacks it chemically as well. Therefore, a dense and mechanically strong crucible that is highly resistant to chemical attack is required. Silicon carbide crucibles provide excellent resistance to elevated temperature erosion and to chemical corrosion. Also, when isostatically pressed, crucibles form a random arrangement of the graphite in their structure. This contributes to creating denser products that can survive erosive and corrosive conditions more effectively.

Many refining and metal treatment processes used with other nonferrous metals also call for a mechanically strong and chemically resistant crucible.

In refining and melting precious metals, it is particularly important that the crucible you use provide clean metal by incorporating non-wetting properties. That means that the crucible must be well sealed against metal penetration. This characteristic is imparted by having a dense crucible material structure and a durable protective glaze.

Fig. 6. This micro-section shows a fired-on refractory coating designed to resist metal and flux penetration of the crucible wall and to prevent metal, oxide and slag adherence to the internal surface of the crucible.

Slag and Dross Removal

A dense, non-wetting crucible also will help reduce slag and dross accumulation and will make it easier to clean the crucible when it is empty.

Emptying the Furnace

Crucibles for melting and holding molten metal that is dipped out of the furnace need to be designed for easy access to the metal and with high thermal efficiency. This allows the furnace to hold the metal at the proper temperature with minimal fuel or power use.

Crucibles for furnaces that are tilted for pouring often require integral pouring spouts that provide the reach and accuracy needed for the pour.

Conclusion

With a full and detailed understanding of all aspects of your metal melting and/or holding operations, you and your crucible supplier will be well positioned to select a crucible product that meets your specific operational requirements and provides a consistently longer service life.