The subject of high-temperature alloys encompasses both cast and wrought products that are available from a number of qualified suppliers. The intent of this article is to provide a simplified overview of the basic requirements necessary for selection of alloy systems for use in thermal processing applications running from -320°F (-195°C) to 2250°F (1225°C) and beyond. The information is presented for the purpose of aiding those in the selection process who have not had the opportunity to work with these alloys in great detail.

More detail can be obtained from a number of sources and standards from organizations such as SAE International (www.sae.org), ASTM International (www.astm.org) and the Alloy Casting Institute to name a few. There are many other sources of technical and research information specific to a given application such as from the many suppliers of these materials.

Design Considerations
In selecting materials for heat-treatment applications, whether they are for interior components in furnaces, ovens, quench baths or heat treat grids, baskets and fixtures, a number of property factors should be considered (Table 1). To obtain the most cost-effective design requires a thorough understanding of the service conditions under which the alloy(s) will be exposed. Important considerations include:

1. Normal operating (exposure) temperature as well as the maximum (and minimum) usage temperatures
2. Metallurgical stability over the expected duty/thermal cycle (period, frequency and rate of heating/cooling)
3. Thermal expansion characteristics
4. Fabrication (or casting) methods (with respect to development of thermal gradients in the material)
5. Design with respect to applied load(s), repetitive force and transfer of the load to the load bearing members
6. Manner of loading, support and (external) restraints
7. Required vs. desired life
8. Environment(s) to which the alloy will be exposed
9. Availability
10. Cost versus life

A Word of Caution
Technical data describing the properties of heat-resistant alloys provides important guidelines to alloy selection, but predicting the behavior of an alloy over long-term exposure to the temperature environment is a complex process. This behavior is not always predictable, and looking at room-temperature properties most often has little relevance to the performance of the actual design under elevated temperature operating conditions. Furthermore, the room-temperature properties may be subject to considerable change after even brief exposure to service temperatures and cyclic conditions. In addition, selection and use of acceptable but not optimized alloys due to time constraints, cost, lack of familiarity or an unproven track record may be a necessity, but the search for and trial of better materials is an important undertaking.

Alloy Selection Criteria
Heat-resistant alloy is primarily selected for the ability to perform a function in extreme-temperature environments. The measure of performance is different in...
each case and varies as the environment changes. In many applications, high temperature creep data (1% creep in 10,000 hours) and/or stress rupture data provided by manufacturers is a relevant method for comparison of the differences between alloys used for heat-treating applications. Over time, however, creep may lead to excessive deformation and even failure (fracture) at stress levels much lower than those determined at room temperature and at elevated-temperature short-duration tensile conditions. When the degree (rate) of deformation is the limiting factor, the design stress at temperature should be chosen below that which produces that limiting rate (limiting creep stress) or below the stress which will produce that limiting degree of deformation in a given time.

Hot strength is a measure of strength at the operating temperature and the ability to resist deformation or attack of atmospheres in a given thermal environment. Creep is a measure of a combination of failures such as distortion, thermal fatigue, thermal shock, carburization and atmospheric elemental attack on the adhesive components and formations of the metal matrix.

Another Word of Caution

Care must be taken to properly interpret creep and stress rupture data as values are often extrapolated from shorter-time or lower-temperature tests. This fact must be considered when comparing alloys. Also, emphasis is often placed on only one or two mechanical properties while others of equal or greater importance may be overlooked. If creep and stress rupture were the only mechanical properties of importance, all heatresistant alloys would be supplied in the solution annealed condition. Thermal fatigue and thermal conductivity, however, are responsible for many failures in furnace applications. Failure to understand these factors in the design of alloy components may result in thermal strains far in excess of those experienced due to mechanical loading.

Room-temperature damage is another example. One of the inherent advantages of cast alloys is high-temperature strength, but seldom is strength alone the only factor to consider. Rough handling (such as pounding on or tossing/dropping cast grids or fixtures) may result in failure due to the brittle nature of the casting rather than from thermal fatigue brought about from stress rupture or creep. Wrought-alloy baskets are not necessarily the solution since these are often pounded back into shape after repeated cycling resulting over time. Failure typically occurs at weld joints that have become sensitized in service and is not due to strength or fabrication issues.

Effect of Alloying Elements

The basic alloying elements and the primary reason for their selection as components of cast alloys and wrought alloys can help the user understand how these alloys effect the variety of chemistries offered by manufacturers. The general effect of the various alloying elements is summarized below.

• Nickel is used in most grades of heat-resistant alloys and can range from a fraction of a percent to grades where the percentage exceeds 75%. Nickel serves as a strengthening and austenite stabilizer. It also confers resistance to oxidation, carburization, nitriding and thermal fatigue. Nickel also improves weldability. The use of high nickel alloys should be avoided in the presence of sulfur or chlorine, especially in reducing atmospheres.

• Chromium provides the basic oxidation resistance for heat-resistant alloys. It is normally present in the range of 10–30%. Chromium is also an active participant in the precipitation of carbides. These carbides account for much of the strength of these alloys at high temperatures. Chromium also promotes the formation of ferrite.

• Carbon accounts for the strength differences that exist between cast and wrought heat-resistant alloys. It is undoubtedly the most important of the minor alloying elements used in cast heat-resistant alloy. It can be present from 0.15–0.75%. As a generalization, carbon can be expected to increase the hot strength and creep resistance while reducing the cold ductility. Carbon is a potent austenite stabilizer.

• Silicon is normally present in heat-resistant alloy in the range of 0.50–2.50%. It is primarily used for improvements to carburization and oxidation resistance. Silicon serves several purposes in the melting of heat-resistant alloys. Silicon is a ferrite former. Excessive levels of silicon lower creep strength and shorten creep rupture time. Silicon levels exceeding 2.5% also reduce weldability.

• Nitrogen is known to confer hot strength and promote formation of austenite. It is normally present in amounts of less than 0.15% and is required to be less
than 0.06% in some petrochemical applications.
• Manganese is normally added for steel-making and casting purposes. It has negligible effect on physical properties at the normally used levels of less than 1.5%.
• Molybdenum improves high-temperature strength in alloys. Molybdenum is a ferrite stabilizer. Elevated levels of molybdenum can lead to catastrophic oxidation failures in certain atmospheres. For this reason, levels greater than 0.50% are discouraged for many heat environments.
• Tungsten improves high-temperature strength like molybdenum. However, tungsten does not have the adverse effects on oxidation resistance like molybdenum. Tungsten tends to retard the coalescence of strengthening carbides. Tungsten is optionally added at levels up to 5.0%.
• Niobium (columbium) is also a strengthening element and forms niobium carbides. Niobium carbides are stable at high temperatures and offer improved thermal-fatigue resistance. Weldability is also improved as the niobium modifies the primary carbide geometry. Optimal levels are 0.5 – 1.0% and not to exceed 1.7% as niobium is subject to high oxidation rates. Elevated levels may reduce the oxidation resistance of an alloy.
• Cobalt is a very effective contributor to hot strength and resistance to creep. It is an expensive addition and normally added in the 0.15% - 0.50% range.
• Iron is the economical base element in most heat-resistant alloy grades.

Cast versus Wrought
Both production methods have advantages and disadvantages (Table 2). In many designs, either cast or wrought alloys may
be used, so both should be considered. Since similar compositions in cast or wrought form vary in physical properties and initial costs, their advantages and disadvantages for the intended application are important considerations.

Final Thoughts
More sharing of practical information about high-temperature alloy performance under the broad spectrum of heat-treating applications is needed throughout the industry.

For his part, the heat treater must keep better records of the service history of his grids, baskets, fixtures and internal furnace components, including a history of duty cycles as a function of application, performance life and failure modes of the alloys. For their part, the alloy fabricators and casters must help interpret this field data, adding their technical expertise on alloy design and help design more meaningful tests. As a whole, the industry must become better educated so we are able to understand how to apply the alloys we have and work as partners in the development of new alloys to keep pace with the changing nature of the heat-treating industry. IH

References
3. Mr. Steve Ellison, President, North American Cronite, Inc., private correspondence.

Additional related information may be found by searching for these (and other) key words/terms via BNP Media LINX at www.industrialheating.com: High temperature alloys, creep strength, hot strength, stress rupture, cast alloys, wrought alloys, baskets, fixtures, grids, carburizing, carburization resistance, corrosion resistance, heat treating.