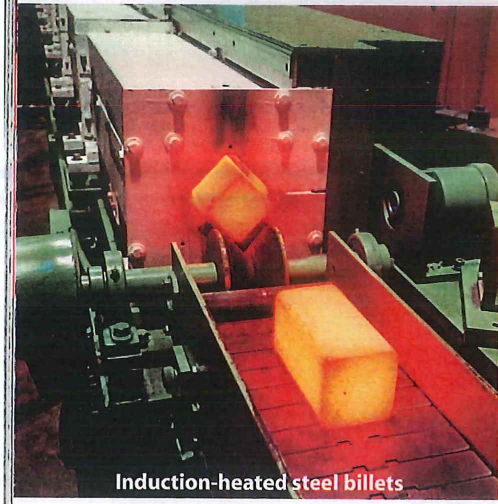

Hybrid Heating: Induction + Gas Furnace vs. Gas Furnace + Induction

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Under certain circumstances, hybrid heating using both gas and induction furnaces can be desirable and cost-effective. The issue of whether to use induction followed by gas heating or gas heating followed by induction is considered here.

Temperature greatly affects the formability of metals to obtain desirable shapes. There are many ways to heat metallic materials, including the use of induction heaters, gas-fired furnaces, infrared heaters, electric and others. Each method has its own advantages and limitations. Steel components by far represent the majority of warm- and hot-worked parts (Fig. 1). At the same time, alloys of Al, Cu, Co, Mg, Ni, Ti and other metallic alloys and superalloys can also be effectively induction heated.

Call for Hybrid Designs

In some cases, hybrid designs consisting of a combination of an induction heater and a gas furnace can offer advantages. This would be the case when, for example, a customer already has an existing gas furnace and plans to expand its business, increase its production rate and/or process different workpiece sizes and alloys that could require higher target temperatures.

There are two typical hybrid designs:

- Induction heating (IH) followed by heating in a gas furnace
- Steel preheating in a gas furnace to elevated temperatures (e.g., 800-900°C) followed by heating to final temperature using induction heaters

Both approaches have their own advantages and can provide an attractive blend of cost-effectiveness, space savings and technically advantageous processing.

Hybrid Design A – Induction Followed by a Gas Furnace

Induction provides the rapid and highly efficient electrical heating of ferromagnetic materials (e.g., carbon steels). Coil electrical efficiencies often surpass 80-85%. Upon exceeding the Curie point (at which materials lose their magnetic properties), heating efficiency decreases to some extent and much deeper heat generation occurs, which intensifies the heat flow toward internal regions of the workpiece and its core.

After receiving the majority of needed thermal energy by an induction system, a workpiece can be transferred to a gas furnace (Fig. 2) that could provide only a minor rise of the billet's mean temperature. The gas furnace primarily acts as a holding furnace for achieving the required volumetric temperature uniformity.

This approach can be particularly beneficial when designing systems to heat irregularly shaped workpieces or components with various masses and complex cross sections (including triangular, trapezoidal, rhomboid, hexagonal, polygonal, etc.). The ability of induction heating to act as a booster and result in highly efficient and rapid bulk heating is attractive since it allows a throughput increase. It also dramatically reduces scale formation because of the reduced time at which the steel surface is exposed to high temperatures.

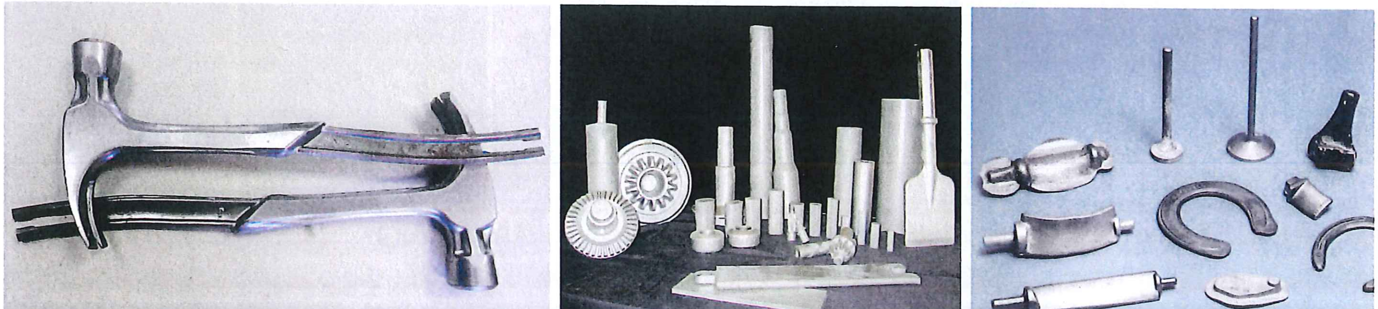


Figure 1. Induction heating is used to produce an assortment of steel parts.

the required thermal conditions more rapidly as compared to fuel-combustion flame heating. Therefore, the workpiece's surface remains at high temperature for a considerably shorter time, resulting in a measurable reduction of scale.

It is also easier to incorporate the protective atmospheres into the design of induction systems, particularly when vertical inductors are used. In such cases, an inductor can be encapsulated completely or partially using a sealed chamber.

The capability of InductoForge technology (Fig. 5) to allow an instant power redistribution along the heating line for different production runs and to minimize the time that the metal is exposed to high temperatures is essential for scale reduction.

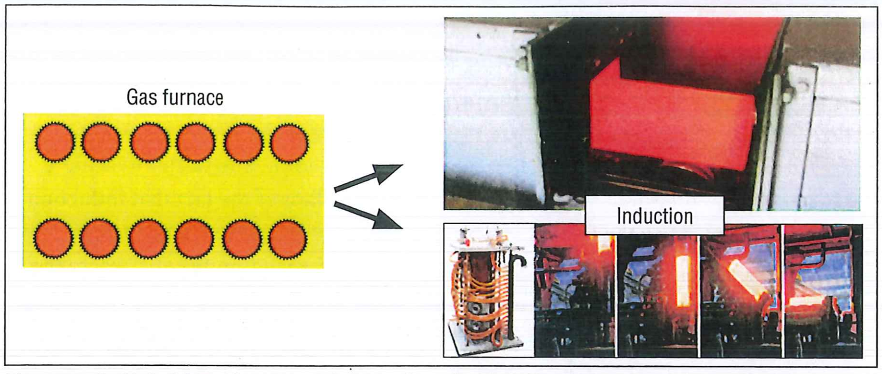


Figure 3. In Hybrid Design B, gas furnace heating is followed by induction furnace heating.

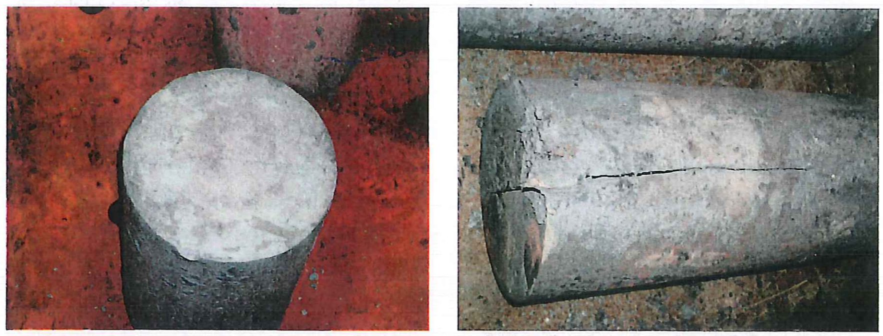


Figure 4. Radial and longitudinal cracks may be a concern when heating metals with low toughness.

Figure 5. InductoForge induction heating system

A Good Question

A customer approached me with the following question: "We process copper-alloy billets in our factory. Gas furnaces have been used to heat copper-alloy billets (grades C14500, C44300, C64200). Billet diameters are within the 200- to 240-mm range. The maximum temperature of our furnace is 860°C (1580°F), which is sufficient for these jobs. However, we are expanding our business and will process grades (e.g., C71500, C63000) that require temperatures of 950-1050°C. Could we use our gas furnace for billet preheating and then use a gantry system to move billets to an induction heater for final heating?"

The simple answer is yes. The hybrid approach will help reduce your capital cost because your new induction system will only require raising the billet mean (average) temperature less than 200°C. Depending on the required production rate and temperature uniformity (surface-to-core and end-to-end), you may use a number of static induction heaters to reach target temperatures. Keep in mind that if the lengths of your billets vary noticeably, you will need to properly control electromagnetic end effects by applying adjustable turns, magnetic-flux extenders or flux concentrators. Considering the diameters of your billets, the use of low frequencies (50-120 Hz) will be appropriate.

The challenges with the induction heating of some copper alloys (e.g., C71500) are with their extremely low thermal conductivity, which is more than 14 times lower than that of pure copper and more than 12 times lower than the C14500 alloy processed now. Therefore, much lower surface-to-core heat transfer will occur, requiring sufficient time to compensate for the lack of thermal conduction. Besides that, the electrical conductivity of C71500 is only 4.6% that of pure copper. This increases both electrical efficiency and depth of heat generation, which may compensate to some degree for the reduction in thermal conductivity.

The electrical resistivity of alloy C71500 is only about 54% of austenitic stainless steel, and its thermal conductivity is about 1.6 times that of stainless steel. Therefore, a response of copper alloy C71500 to induction heating is closer to the response of stainless steel than pure copper. Subtleties of new copper alloys must be addressed when designing an induction heater to be positioned after a gas furnace.

Conclusion

In the past several decades, heating by means of electromagnetic induction has become

Hybrid Design B – Gas Furnace Followed by an Induction Heater

In contrast to Hybrid Design A, forging billets can be initially preheated to temperatures in the 800-900°C range in a gas furnace to take advantage of the lower cost of gas. Then billets can be transferred to a horizontal or vertical induction heater to achieve the final thermal conditions and benefits (Fig. 3). Regardless of the fact that induction heating is applied above the Curie temperature, total heating efficiency for steels is still significantly higher as compared to gas furnaces being often within the 60-75% range.

Besides the advantage of using a lower-cost utility in providing bulk heating, there will be an additional savings resulting from the lower maintenance cost of the gas furnace due to its operating at low temperatures. If only gas or resistance heating is used to achieve steel forging temperatures, noticeably greater temperatures would be required inside the furnace chamber to develop a heat-flux density at the workpiece surface sufficient to provide the needed production rate. This would drastically reduce the trouble-free life of a gas furnace.

This hybrid concept is also attractive when heating alloys that exhibit extreme brittleness. Radial and longitudinal cracks (Fig. 4, left and right, respectfully) may be a concern when heating metallic materials that exhibit low toughness. Cracks may appear due to excessive thermal stresses during the initial heating stage. The permissible magnitude of thermal gradients is a complex function of geometry, chemical composition, prior processing conditions (e.g., as-cast vs. wrought steel), microstructural irregularities, etc.

As-cast steels, for example, are particularly prone to cracking under intense heating and need special attention. Solidification defects (shrinkage, macro- and micro-segregation, porosity), gas defects (blowholes/pinholes, intergranular porosity, entrapped air pockets, etc.), hot tears and other stress risers also have a pronounced effect on the maximum permissible heat intensity during the initial heating stage. A hybrid concept may offer appreciable benefits in such cases.

This hybrid design can also help minimize metal loss due to scale. Scale formation is a major concern to the industry since it has a multidimensional negative impact on overall cost-effectiveness and product and tooling life. Scale detracts from a value-added product, and its elimination or significant reduction is imperative to steel processing companies. Reference 1 discusses several ways to suppress scale formation in steels. One of these is to shorten the time that the workpiece surface is exposed to high temperatures in an oxidizing atmosphere.

Induction heating allows reaching

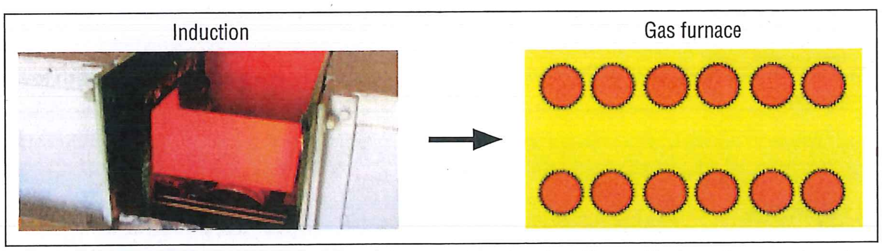


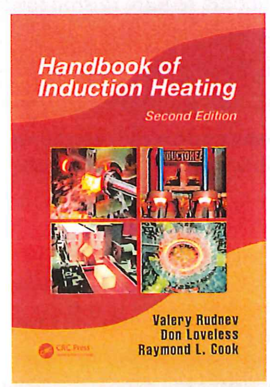
Figure 2. In Hybrid Design A, induction furnace heating is followed by gas furnace heating.

New Resource for Induction Heating and Heat-Treating Professionals

Heating by means of electromagnetic induction is a topic of major significance. The recently published 2nd Edition of the *Handbook of Induction Heating* is the result of an ambitious undertaking to compile an all-new, comprehensive resource on induction heating and heat treating. The majority of materials presented in the first edition have been completely rewritten, and a substantial amount of new materials have been added, including:

- Induction technologies for heating ferrous and nonferrous metals prior to warm- and hot-working, coating and joining. The effect of rapid heating on the kinetics of austenite formation. The impact of prior microstructure, its heterogeneity and the presence of the residuals are reviewed.
- Novel induction technologies for automotive, aerospace, off-road and other industries. Innovations and inventions in equipment design maximizing metallurgical quality, process robustness and machine flexibility. Insights of induction hardening, tempering and stress relieving.
- Simple solutions for typical challenges, failure analysis and prevention of cracking and excessive distortion.
- Modern medium- and high-frequency power sources for induction heating needs.
- The modular designs in IH of metallic materials prior to forging, extrusion, rolling and upsetting. Concept of true temperature control and avoidance of surface and subsurface overheating.
- Crucial tips executives must know regarding computer modeling of induction heating.

The 2nd Edition embarks on the next step for cost-effective and energy-efficient induction processing, providing numerous case studies, ready-to-use tables and simplified formulas. It is intended to reach a wide variety of readers, including practitioners, students, engineers, metallurgists, managers and scientists.



an increasingly popular choice for the warm- and hot-working of metals. In most cases, induction is used as a single source for heating metals. At the same time, there are applications where hybrid approaches might provide certain benefits. As a general rule, when dealing with massive complex geometries and materials that exhibit sufficient toughness and ductility (particularly during the initial heating stage), Hybrid Design A (induction followed by a gas furnace) might be beneficial. In contrast, when dealing with classical-shaped parts made of brittle materials (high-carbon steels or as-cast metallic materials), Hybrid Design B (gas furnace followed by induction) might be considered.

References

1. V. Rudnev, D. Loveless, R. Cook, *Handbook of Induction Heating,* 2nd Edition, CRC Press, 2017, 750p.

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