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A part expensively manufactured by melting, hot rolling or forging, annealing, rough machining, teeth cutting and grinding is essentially useless and of little to no value without heat treatment. Amazingly, the cost for a manufacturing step that adds such high value is only a fraction of the total production costs – generally in the range of no more than 5%. This percentage, however, increases to roughly 15% of the costs per part if all further post-treatment process steps inherent with, or caused by, heat treatment – such as cleaning, blasting, straightening and/or grinding – are taken into account.

Therefore, a noticeable reduction of the manufacturing costs is only possible by minimizing the distortion of parts. For this, all the influencing parameters like steel melting, forming of the parts, uniformity of microstructure and hardenability, as well as the natural factors of the heat-treatment process – positioning of the parts in the load, uniformity of heating, carburizing and heat extraction during quenching – need to be analyzed and optimized if one is to continually produce quality parts in batch atmosphere furnaces.

When producing quality parts, we are primarily concerned with properly utilizing the carburizing and quenching processes and applicable modern technology. From optimizing controls and quenching systems to the benefits of establishing temperature and gassing uniformity, here are some tips highlighting how to make the most of your processes and atmosphere furnace.

**Optimizing the Carburizing Process**

While there are currently two industrial carburizing processes – gas carburizing in atmosphere furnaces and low-pressure carburizing in vacuum furnaces – both have the same aim: to carburize all workpiece elements in a load uniformly to the same surface carbon (C) content and to the same case depth.

Atmosphere carburizing runs a series of different process steps. Knowledge of these steps is necessary for achieving repeatable work and uniform carburizing.

1. **Gas reactions:** Generation of the carburizing gas components in the atmosphere
2. **Convective gassing:** Transport of the carbon-containing molecules in the gaseous phase to the component
3. **Diffusion transport:** Transport of the carbon-containing molecules through the boundary layer (v=0) at the component surface
4. **Dissociation and adsorption:** Dissociation of the molecules at the component surface
5. **Absorption:** Taking up of the carbon by the component surface
6. **Diffusion:** Transport of the carbon into the component

Overall, the gas reactions that take place in the carburizing atmosphere are many and varied. Taking into consideration the six process steps listed above, ideal carburizing conditions exist if temperature and gassing uniformity, flow over the components and fast reaction kinetics occur evenly throughout the treatment chamber. One can positively influence the quality of components produced by achieving ideal conditions in these areas.

**Temperature Uniformity**

A uniform temperature is one of the first (and most essential) steps for ensuring parts emerge with an ideal carburizing
depth — and thus higher quality. In efficient batch atmosphere furnaces (such as the Ipsen ATLAS®), temperature uniformity of at least ±13°F (±7°C) is maintained in the heat chamber. Upon completion of the heating phases, all components in the austenitic phase are at the same temperature.

Efficient burners — like Ipsen’s Recon III burners — can enhance the heating of batch furnaces. These burners are single-ended recuperative tubes (SERT) fitted with special ceramic inner tubes. The burners increase thermal efficiency up to 75% simply by recovering the heat from the exhaust gases and reducing time to recovery of the hot-zone temperature. Distinguished by low noise levels, high durability, low maintenance and easy installation, these modern burners provide ideal heating while optimizing gas consumption. Reliability comes from excellent furnace designs. One example of this is if one of the burners is down in the middle of a cycle, the other burners are adaptive and will compensate so that excellent uniformity can still be achieved throughout.

However, it’s important to realize that achievement of temperature uniformity is not possible without improved gas flow over the components. You must have a well-planned circulation system to achieve excellent flow around components and, thus, maintain temperature uniformity.

Gassing Uniformity
The positive convective properties that result in excellent temperature uniformity within the load area also result in improved heat transfer to the load and homogenous process atmosphere. Figure 1 portrays how the combination of minimum temperature deviation within the load area and the homogenous process atmosphere results in minimized case-depth deviations throughout the load.

Continuous introduction of the carrier gas and controlled additions of the enriching gas result in a furnace atmosphere capable of producing carburized parts with the specified percent of surface carbon and to a specified case depth with highly repeatable results (Fig. 2).

Intuitive control software, such as Ipsen’s Carb-o-Prof® system, can assist in maintaining balance by regulating, documenting and archiving the carburizing processes in atmosphere furnaces. No matter the case — if your power goes out or some other unforeseen event occurs — the software is able to adapt the process to the changing circumstances, preventing the potential waste of parts and resources. Even before actually processing the load, users are able to generate a potential recipe and immediately review the process results using the advanced simulation software.

Specifically, the software monitors and controls uniformity of the C-level within the atmosphere, which, through supervision, maintains a tolerance of ±0.05% C for the workpiece surface carbon content. This consistency of the atmosphere’s carburizing effect results in uniform carburizing of the surface layer, as shown in the example of a gear wheel in Figure 3.

When striving toward uniform carburizing, it is important to remember that temperature and gassing uniformities are interrelated — it is difficult to meet one parameter without influencing the other.

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**SuperQuench® — Increasing Productivity, Reducing the Hardness Spread**

Regardless of whether you’re quenching bulk or very dense loads, Ipsen’s SuperQuench® system tackles even the most challenging alloy by reducing the spread of hardness values and increasing the overall production of parts. With larger propellers, stronger drive motors and optimized baffling, it provides an oil bath for the heat treatment of widely varying steel grades, including low-alloyed steels. In addition, each individual agitator has been allocated a separate flow-control system so that the entire load is reliably, uniformly and quickly quenched — all of which contributes to an improved hardness distribution and high-quality parts.

Overall, the SuperQuench system produces higher oil flows with improved speed. The system’s flexibility allows the oil flow to be adapted to the section size, material and the load density to be quenched. For optimal heat-treatment results, the flow velocity is not kept constant during the whole quench cycle but segmented in as many steps as necessary. Other strengths of SuperQuench include its contributions to uniform hardening, reduced distortion, and optimized quench speed and heat extraction.

**Uniform Hardening of Components**

Each agitator motor is equipped with a variable-frequency drive, allowing the separate speed adjustment of each motor in the range of 10-60 Hz. Depending on the oil viscosity, running the motors up to 60-70 Hz is possible for a limited period of time.

As the oil flow is better restricted to the load area via baffles implanted on all four sides of the load in the oil tank, a high oil flow is maintained — even with very dense loads. This high oil flow results in uniform oil-flow velocities between the top and bottom area of the load, including those in the top tray. Thus, the utilization of the SuperQuench process reduces the spread of the hardness values while also increasing the productivity of the sealed-quench furnace because more trays can be used in each load. In practical applications, it is possible to achieve an increase in productivity by up to 50% (compared to a sealed-quench furnace with a standard oil-quench system).
Ceramic Muffles
Batch atmosphere furnaces possess several features that help achieve both proper temperature and gassing uniformity during various processes. One such feature is the ceramic muffle, which is made of silicon carbide and can optimize the performance of all heat-treating processes. Atmosphere furnaces (e.g., Ipsen’s ATLAS) use ceramic muffles to shield the load from direct heat and to facilitate uniform temperature distribution throughout the material being hardened.

The muffle provides a temperature uniformity that is especially important in case hardening because it controls the depth of penetration and carbon concentration. In addition, the muffle’s ability to provide optimal circulation and a constant directional flow assists in evenly soaking the load. Beyond temperature and gassing uniformity, the next critical step is optimizing the quenching process.

Optimizing the Quenching Process
Older quench systems for batch atmosphere furnaces used to possess little flexibility with respect to varying the quench intensity. Experience shows there is significant potential for optimizing a uniform quench in oil. The implementation of these techniques has produced a more uniform hardening of parts – especially of gear components – with an improved microstructure and reduced distortion.

Today’s requests of adapting the quenching intensity of quench systems to the needs of different components – specifically hardenability and minimization of distortion – have also led to the increased production of quality components.

Recipe Database
Programmed with hundreds of available recipes, the database allows the most important recipe information to be registered via quick, simple input. Faulty inputs are prevented by appropriately limiting the input range, thereby maintaining a safe operation and avoiding excessive consumption. As a result, recipes are generated in an easy, consistent manner that focuses on the carburizing/hardness results and prevents input errors.

Simulation with C-Profile Optimization
A standard feature of the Carb-o-Prof is its simulation function. Essentially, it computes the materials’ expected carbon profile according to the entered parameters and displays the results, both as a table and as
contact with a mass significantly hotter occurs when a liquid, which is in near Leidenfrost effect. This phenomenon por phase, also commonly known as the quench system.

It is important to be aware of the variance quench oil – as is normal in sealed- quench furnaces today – a high oil-flow velocity best achieves a high, uniform cooling rate on the entire surface area of a part. This speeds up the breakdown of the vapor film in areas of less flow, producing a more uniform, faster quench.

Higher oil velocities considerably improve the uniformity of heat extraction. Depending on the thickness of the part and the hardenability of the respective steel, the influence of the flow velocity can also result in further quality improvement of the part.

Reducing Distortion
The goals for distortion-optimized quenching can generally be defined as follows:

- Uniform heat extraction over the whole surface of the part
- Uniform heat extraction on every part within one load
- Material- and part-adapted timing to control the quench intensity

These goals are realized throughout the quenching cycle. The first part of the quenching cycle uses a maximum oil flow so that a quick vapor-film breakdown occurs and a high heat extraction is realized in the nucleate boiling phase – all of which prevents the production of ferrite and pearlite. The second part of the quenching cycle reduces the cooling rates to allow temperature homogenization between the surface and core before martensitic transformation starts. This equalizes thermal and transformational stresses, which produces less distortion. As Figure 6 demonstrates, these innovative systems allow you to achieve optimized performance and produce quality components as compared to a conventional oil bath.

Conclusion
When carburizing/through-hardening and quenching parts in a batch atmosphere furnace, it is essential to achieve uniformity of temperature and gassing, optimize the flow over components, and aim for ideal quench speeds and heat extraction by utilizing various high-performance systems. This allows you to produce high-quality parts with reduced distortion, as well as achieve competitive overall manufacturing costs via heat treatment.

In addition, through the use of modern technology – such as Carb-o-Prof and SuperQuench systems, ceramic muffles and Recon III burners – one can achieve ideal end results when using carburizing/through-hardening or quenching processes. In the end, the enhanced design and control of such technologies allows you to positively impact your processes, as well as utilize the tips provided for producing quality parts. IH

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