Enhancing the Performance and Durability of Forged Steel With Annealing

By Ray Harkins and Jay Desai

Steel forging holds significant importance in developed economies around the world. It is used to shape raw materials into precisely designed components that often have critical performance requirements. Due to their strength, durability, and reliability in harsh environments, forged steel components are utilized in a wide range of industries including aerospace, automotive, defense, and construction.

The steel forging process involves the design or selection of an appropriate steel grade based on the desired properties of the finished part; a heating method and processing temperature range to temporarily increase the material's malleability; and the tooling required to create the desired shape. However, the intense forces and temperatures of forging often result in non-uniform microstructures within the material, increasing the internal stresses and irregularities that adversely affect the part's performance in its final application.

Hence, most steel forgings undergo heat treatment to achieve the uniform microstructure needed for optimized mechanical properties and component performance.

Spheroidize annealing furnace. Photo courtesy of Ohio Star Forge.

Heat treatment is a controlled process where components are subjected to carefully designed heating and cooling cycles that influence the microstructure needed to achieve these optimized properties. The heat treatment parameters – the various temperatures and times built into the heat treatment process -- are unique for each steel composition, and are selected to obtain the yield strength, hardness, toughness, and wear resistance for the given application. These processing parameters are often the keys to obtaining the requisite part quality and reliability thresholds.

One of the most common heat treatment processes for steel forgings is annealing. Annealing is the process of heating steel to 40 to 50°C above its so called "critical temperature", and then cooling it in a slow, controlled manner. The critical temperature of steel, often referred to as AC1, is the point at which important structural changes take place in the material's crystal lattice. And for plain carbon steel, this starts at about 723°C and is primarily influenced by the material's carbon concentration. Impurities, alloying elements, and other factors can affect it as well.

Annealing softens steel, enhances its malleability, increases its ductility and toughness, and is often associated with the development of a uniform microstructure and grain refinement – the reduction of the size of the crystalline structures within the material.

There are several types of annealing, each tailored to specific steel grades and desired microstructures. The most common types of annealing are full annealing, process annealing, stress-relief annealing, and spheroidizing annealing.

Full annealing is performed to increase the ductility of steel and obtain a specific type of microstructure called coarse pearlite. It involves heating the steel to a temperature above its critical range for a specified duration, then slowly cooling it. Full annealing is usually performed for forged parts made from medium (0.2% to 0.6%) and high (0.6% to 1.4%) carbon steels.

Process annealing is used to obtain strain-free grains for better deformability. In this process, the steel forging is heated to a temperature below its critical point, held there until recrystallization is complete, and then slowly cooled. This method reduces the hardness and improves the machinability of the forging.

Stress-relief annealing is designed to improve the forging's dimensional stability and minimize its risk of cracking. It is also performed just below the AC1 to remove residual stresses generated during forging and is followed by slow controlled cooling.

And lastly, spheroidizing annealing, also referred to as spheroidization is the annealing treatment used for high carbon and alloy steels to improve their machinability prior to final hardening and tempering. This heat treatment is performed just below AC1 for long durations to convert cementite (a hard, brittle phase) into softer spheroids.

Annealing is an adaptable and indispensable heat treatment process for enhancing the performance and durability of steels. By altering its microstructure and mechanical properties, annealing enables steel to meet the rigorous demands of diverse industries. Its ability to reduce brittleness, increase ductility and improve machinability makes annealing a fundamental technique in modern metallurgy. And in an era where engineering materials continue to evolve, the timeless practice of annealing remains a cornerstone in the quest for stronger, more durable, and more versatile steel products.

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