

TECHNICAL WHITEPAPER

FORGING AT SCALE

Capacity, Metallurgy and Quality Benchmarks for
Large Open-Die and Rolled Ring Forgings



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Executive Summary

Claims about forging capacity are often reduced to press tonnage, maximum diameters or listed part weights. While these metrics are easy to publish, they do not determine whether a supplier can consistently achieve required mechanical properties, grain flow integrity or inspection standards in large, critical components. True forging capability is defined not by equipment size alone, but by metallurgical control, deformation strategy, heat treatment execution and inspection depth.

At the same time, concerns about domestic forging shortfalls are not supported by current industry data. The Forging Industry Association 2024 Capacity Utilization Study shows that U.S. forgers are operating at roughly half of available capacity, with significant open capability across key sectors including defense. Substantial existing infrastructure can absorb additional demand, indicating that the issue is not lack of national capacity, but proper alignment of technical requirements and supplier qualification.

This paper outlines the factors that separate nominal capacity claims from true large forging capability. These include disciplined ingot sourcing and melt practice control, demonstrated deformation ratios that ensure grain refinement and internal soundness, heat treatment systems designed for heavy sections, advanced in house inspection and testing capabilities and alignment with application driven risk profiles in nuclear, energy and defense markets.

For buyers of large forgings, the evaluation process must move beyond press ratings and marketing specifications. A rigorous technical review of upstream metallurgical controls, forging execution, thermal processing and quality systems is essential to ensure long term performance and compliance in high consequence applications. When these factors are properly assessed, it becomes clear that domestic suppliers with the right technical depth are fully capable of meeting demanding national requirements.

Why Forging Capacity Claims Are Misleading

Many forging suppliers list press tonnage, maximum diameters or part weights. These figures alone do not determine whether a forging can meet mechanical property, grain flow and inspection requirements.

Common gaps include press tonnage without deformation ratios, maximum part size without ingot sourcing transparency, alloy availability without melt practice details and inspection claims without actual NDE limits.



The Forging Industry Association 2024 Capacity Utilization Study¹ shows that domestic forgers are operating at just over half of their available capacity, with current utilization averaging 51.2 percent and forecasted utilization at 53 percent. Even in the defense sector, which reports the lowest utilization at 41 percent, the study notes that companies have ample capacity to take on additional defense work if demand materializes. Across the industry, firms report 35 to 70 percent open capacity, and many indicate that no immediate capital investment is required to increase output because existing equipment and facilities can absorb more work. The data clearly demonstrates that U.S. forgers have substantial unused production capability and stand ready to meet increased national demand across defense, infrastructure, energy and transportation markets.

Ingot Procurement and Metallurgical Control

Ingot quality is the foundation of any large forging. Variability in melt practice, chemistry control and solidification directly influences internal soundness, grain structure, segregation patterns and ultimately the mechanical properties of the finished component. Because large forgings cannot “forge out” fundamental metallurgical defects, upstream control at the ingot stage is critical to downstream performance, inspectability and yield.

Melt process consistency is a primary driver of quality. Other critical ingot factors include chemistry control, ingot size availability relative to final forging dimensions and supplier relationships that allow consistent ingot access. Chemistry control must go beyond nominal specification compliance. Large-section forgings require disciplined management of alloying tolerances to account for segregation during solidification and subsequent redistribution during forging and heat treatment. Macrosegregation and centerline chemistry variation risks increase with ingot diameter, making initial melt uniformity and solidification control especially important for heavy cross sections.

Ingot size and geometry must be aligned with final forging dimensions and reduction requirements. Proper ingot selection ensures sufficient forging reductions to break down cast structure, close porosity and refine grain size while maintaining directional properties where required. Oversized ingots can increase internal segregation risk and cost, while undersized ingots may limit achievable mechanical properties due to insufficient working.

Solidification practices and cooling rates further influence internal quality. Control of hot tops, feeding systems and solidification time helps mitigate shrinkage cavities, piping and centerline porosity. For critical applications, traceability to specific heats and ingot lots enables metallurgical accountability throughout the supply chain.

¹ Forging Industry Association. (2024). FIA 2024 capacity utilization study. Harbour IQ Powered by Wipfli.



Finally, strong supplier relationships are essential to secure consistent access to qualified ingot sources, particularly for specialty alloys and large diameters. Long term partnerships support stable melt practices, predictable lead times and collaborative resolution of metallurgical challenges. In high consequence industries such as defense, energy and aerospace, this upstream alignment between melt source and forging producer is fundamental to delivering reliable, repeatable performance in large scale components.

Deformation Ratios and Grain Refinement

Mechanical properties in large forgings are driven by effective deformation, not press tonnage alone. While press capacity determines the ability to move material, it is the magnitude, distribution and sequencing of strain that ultimately governs internal structure and performance. Achieving that effective deformation depends heavily on the judgment and experience of skilled blacksmiths and forging operators. They control workpiece positioning, bite size, reduction per pass, rotation and reheating intervals to ensure strain penetrates the core rather than remaining concentrated at the surface. Experienced smiths recognize how material responds under load – adjusting techniques in real time based on temperature, resistance and geometry – to promote uniform grain flow, close internal discontinuities and avoid defects such as laps or strain induced cracking. In large forging operations, the press provides the force, but it is the skill of the blacksmith that translates that force into the precise deformation patterns required to achieve consistent mechanical properties throughout the section.

Adequate deformation promotes grain flow continuity that follows the contour of the part, improving fatigue resistance, impact strength and directional toughness. High cumulative strain breaks down the as cast dendritic structure, reduces chemical segregation effects and refines prior austenite grain size before heat treatment. This refinement enhances hardenability response and contributes to more uniform mechanical properties throughout the cross section. Importantly, deformation also helps close internal porosity and heal minor discontinuities through plastic consolidation

For large forgings, careful control of reduction per pass, forging temperature and strain rate is essential to maximize metallurgical benefit while avoiding cracking or excessive grain growth. When properly executed, optimized deformation practices transform the ingot's cast structure into a refined, homogeneous forging capable of meeting demanding mechanical and ultrasonic requirements.

Heat Treatment at Scale

Heat treatment for large forgings introduces challenges not present in smaller components. Furnace uniformity, controlled heating and cooling rates, quench capability and distortion management must all be evaluated relative to part size.

As forging size increases, it becomes more difficult to heat and cool the part evenly from surface to core. Large sections require longer soak times to ensure uniform temperature before



transformation begins, and poor temperature control can result in uneven hardness, residual stresses or inconsistent microstructure. Quench systems must provide adequate volume and agitation to achieve the required cooling rate across the entire section, while proper fixturing helps limit distortion during thermal cycling. Effective large scale heat treatment therefore depends on the right equipment, careful process control and strong metallurgical oversight to consistently meet specification requirements.

Inspection and Testing Requirements

Advanced non-destructive testing methods such as ultrasonic testing, magnetic particle inspection and liquid penetrant inspection are essential for detecting subsurface and surface discontinuities in large cross sections. For heavy forgings, ultrasonic capability must be scaled appropriately to account for section thickness, material attenuation and required sensitivity levels. In-house metallurgical laboratories that perform tensile, impact, hardness and microstructural evaluation provide immediate feedback on process effectiveness and specification compliance. Additionally, in-house destructive and non-destructive testing reduces lead time and allows faster resolution of technical issues during production. Maintaining certified personnel, calibrated equipment and documented procedures ensures traceability and builds confidence for customers in defense, energy and other high consequence applications.

Application-Driven Requirements

Different industries impose different risk profiles. Nuclear components require extreme material traceability, energy applications demand fatigue resistance and defense programs require repeatability across production lots. These differing requirements influence everything from raw material sourcing and process controls to documentation depth and qualification testing. In high consequence sectors, process validation, lot traceability and long term data retention are often as critical as the mechanical properties themselves. Suppliers must align their manufacturing controls, quality systems and inspection protocols with the specific performance and compliance expectations of each end use market.

Buyer Checklist

Buyers sourcing large forgings should evaluate ingot sourcing, demonstrated deformation ratios, heat treatment capacity matched to part size, inspection depth and experience in critical service industries. They should also assess whether the supplier can provide documented process controls, traceability from melt to finished component and consistent performance across multiple production lots. Equipment capacity alone is not sufficient — buyers should examine metallurgical expertise, operator experience and the supplier's ability to manage risk in heavy section components. A thorough technical review up front helps ensure long term reliability, compliance and performance in demanding applications.



About Scot Forge

Based in Spring Grove, Illinois, USA, Scot Forge is a domestic, 100% employee-owned manufacturer of custom open die, semi-closed die and rolled ring forgings. Starting as a small hammer shop in Chicago in 1893, Scot Forge has more than 130 years of experience in the forging industry. As a small business, we serve multiple industries including national defense, mining, space launch, infrastructure, power generation, nuclear energy, heavy industry and more. From ferrous and non-ferrous forgings, through forge, heat treat, machining, metallurgical analysis, destructive and non-destructive testing to R&D, forge engineering, simulation modeling and conversions from castings and fabrications to forgings, the Scot Forge team has a proven track record in serving our nation's toughest metal challenges, all while meeting budgetary and timeline deliverables.

