

Overview

This symposium was sponsored by ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys. It was organized by Subcommittee A01.06 on Steel Forgings and Billets and was international in terms of both the contribution of papers and the attendance. The object was to reflect on the scope of the work of the subcommittee and its four sections, as well as to provide a forum for the presentation of developments in ferrous forgings. An anticipated outcome of the symposium would be a significant contribution to the range, momentum, and quality of the expertise applied to the standards work of the subcommittee, but this special technical publication will serve more widely as a benchmark on the technology of steel forgings, particularly the larger sizes.

The symposium format followed the organization of A01.06, reflecting that subcommittee's diverse interest in steel forgings. The sessions, then, included general industrial forgings, turbine and generator forgings, pressure vessel and nuclear forgings, and test methods. Assistance was given by Subcommittee A01.08 on Wrought Stainless Steel Products for the session on stainless steel forgings. In the spirit of all ASTM activity, the symposium contributors included those who produce, those who use, and those who have a general interest in forgings, with an added contribution from a forging equipment manufacturer. The subject matter of the papers covers all of the salient manufacturing stages on which the production of quality forgings depends, namely, steel melting, refining and re-melting procedures, control of segregation and solidification in both large and specialized ingots, forging procedures, and achievements which contribute to improved integrity in response to application demands. It is laudable that the symposium was held so successfully at a time when demands on forging capacity were and currently are steadily receding. The trends in heat-treatment procedures for forgings are evident from the details given in several of the papers. Forgings present particular problems for nondestructive test methods because of the range in size and the variety in shape. The papers include reference to immersion ultrasonic examination as well as to specialized techniques for in-service inspection.

As a summary paper on the development and current status of turbine and generator rotor forgings, the keynote address by Curran reflects the growth of the industry in terms of the sheer size of the present-day central generating plant, made possible in part by the steadily improved quality of the forgings. It is indeed fitting that this paper marked the retirement of the author after a distinguished

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career devoted to these essential products. The integrity required in a huge spinning mass of forged alloy steel, confined within a steam chest or stator housing, is not generally subject to debate, and it should come as no surprise that papers concerned with this equipment constituted the longest session of the symposium, the subjects covering not only the rotors themselves but also the generator retaining rings.

The control of segregation in the massive ingots needed to make rotors is specifically the subject of a paper by Kim et al., giving confirmation of the beneficial effects of low silicon practice and adding to the data available on the important subject of ingot segregation. A glimpse of the possible future melt practice for super clean steel for large rotor production is the Electric Power Research Institute (EPRI) paper by Steiner and Jaffee on the manufacture of an experimental Ni-Cr-Mo-V turbine rotor forging. The full evaluation of this rotor is underway, and one challenge will be the assimilation of the evolving requirements into economic manufacture.

The mechanical property requirements of high-temperature steam turbine operation are at odds with those for the lower pressure operation of the same unit, and developments aimed at satisfying both requirements in an acceptable manner recently have resulted in production units being made. The development and manufacture of such turbine rotor forgings are discussed in papers by Yamada et al. and Suzuki et al. and depend on a novel dual heat-treatment procedure. These papers are reference works for this application. In similar fashion, the information included on the advanced technology 1Cr-Mo-V turbine forgings from more EPRI work by Swaminathan et al. and on the new 2Cr-Mo-Ni-W-V steel by Finkler and Potthast for high-pressure rotors will provide a fund of reference data.

The current status for large welded rotors by one of the European manufacturers also is discussed by Pisseloup et al., while the subject of large monobloc forgings in Ni-Cr-Mo-V steels, already touched on in discussion of the ingot segregation control, is addressed in a status paper by Kawaguchi et al., with test data from among the largest rotors produced, including deep-seated notch toughness properties.

A paper by Albrecht et al. on the subject of the Ni-Cr-Mo-V steel commonly used for LP rotor forgings was aimed at mass effects associated with the hardenability of the material and was based on some actual rotor test data, together with test results on test material heat-treated to simulate much larger forgings. As has been noticed often in other such comparisons, the degree of reduction in toughness concluded for large section sizes appears to be in some contradiction with actual measurement. This remains a lively topic for further work.

Many rotor forgings which predate such significant developments as vacuum degassing and ultrasonic examination are still in use. Such units are now commonly examined as far as is possible by modern test methods. The metallurgical examinations reported by Toney et al. of Cr-Mo and Ni-Mo-V rotors taken out of service after nondestructive testing add to the data on the significance of flaw indications. It will be helpful to those responsible for the continued use of older

equipment. The condition of operating power generator equipment is also the subject of a paper by Bellows and Walker. The paper addresses the use of ultrasonic and magnetic particle examination techniques for large rotors. The data obtained is considered with regard to service-related issues such as crack growth.

In the power generator industry, the electroslag remelting (ESR) process has found a niche in the manufacture of both the martensitic and duplex chromium stainless steel rotor forgings. The use of one such alloy for service in the arduous conditions of geothermic power stations is described by Schönfeld and Potthast.

As with the high chromium steels, the ESR process also lends itself to the production of nonmagnetic retaining rings for generator forgings. This highly specialized product requires high integrity to withstand the daunting forming procedures and the demanding service. The paper by Stein and the paper by Rambaud and Cazenave discuss the latest thinking on the materials used and their properties.

In other conventional applications of the ESR process, a large nuclear forging in Type 304 austenitic stainless steel is described by Watkins and Tihansky as is an assessment of an open die test forging in the new modified 9Cr-1Mo steel by Khare and Sikka and by Gelpi. The material is now known in ASTM as Grade F91 for forgings. The information on the latter forging contributes to the data required for designers wishing to use this versatile heat-resisting steel.

The introduction of electroslag remelting under pressure is described in the Stein paper, in the context of introducing nitrogen as well as excluding possible hydrogen sources. There is some indication that this development will see the introduction of new nitrogen-containing alloy steels, but the system may prove to be of great significance (without the addition of nitrogen) in the control of hydrogen, always a problem in the electroslag remelting of high-strength, low-alloy steels, and particularly so with the very low sulfur contents possible with the ESR process.

Forging procedures are covered on both the theoretical and application sides by a paper on forging force requirements with regard to shear resistance of the material by Javorik and by a detailed description of a procedure for manufacturing very large continuous grain flow, marine-type crankshafts by Rut. The latter paper again gives the current status for an established method of forging such shafts.

Thermomechanical processing for austenitic stainless and heat resisting forgings, including some high-strength precipitation hardening grades, is authoritatively described by Kuhlman et al., and an unusual forging application of austenitic stainless and the high-strength A286 material is described by Abe and his coworkers for cryogenic application in a fusion test facility in California. The details on forgings in these specialty steels will be welcomed by those using or working with them.

In the pressure vessel field, the papers included an account by Bocquet et al. on the directionally solidified ingots manufactured by what is known as the LSD process and used for specialized applications. Hollow ingots for pressure vessel

shells and disk-type ingots for large tube sheets are discussed, particularly on the segregation characteristics of these ingot types. It will be of great interest to watch the popularity of these procedures. In particular, the disk-type ingot without hot tops may be the subject for future papers.

The offshore oil and gas industry has developed quality and design restraints as a result of service experience that includes several tragic failures and is faced with the difficulties of working in deep waters. Sophisticated designs requiring material of high integrity are now appearing, and an example of this is in the paper by Whitehouse, while illustrates the use of low-alloy steel forgings for a tension leg platform (TLP) anchor design.

Heat treatment figured heavily in at least two papers in this session, one by Badeau et al. covering the 2 1/4Cr-1Mo material for petrochemical vessel shells, and the other by Skamletz and Grimm on large nuclear power system tube sheets in ASTM 508 class 3 type material. The latter example described the use of the intercritical heat-treatment system to enhance toughness. Standards action to positively admit this type of heat treatment is probably overdue at this time. Another paper from Europe by Austel and Körbe and from Japan by Kawaguchi et al. illustrate the state of development of very large and intricate open die forgings for specialized components for nuclear reactors and pumps. These papers convey very well to designers the forging capability for high-integrity components with the minimum of welds for later in-service examination. Just as the keynote paper gave the review of rotor forgings, the paper by Bernabei et al. on seamless shell course forgings gives an excellent overview of the nuclear forging status.

Forgings, because of their variability in size, shape, and cross-section size, impose specific requirements and restrictions on test methods not encountered or required for the more regularly-sized product forms such as rolled shapes or plate. The development of an immersion ultrasonic examination method for steel forgings and described in the paper by Gensure et al. in the test methods session describes the use of such a system, not currently covered by the methods of A 388,¹ A 418,² A 456,³ or A 745,⁴ all of which are ultrasonic examination methods for forgings. An update on hydrogen in steel forgings by Murphy and Steiner also was included in this session as a review of current thinking on this important subject. Failure analysis commonly is not addressed in a general symposium of this type, but the paper by Ebara and Kubota on forging die failure assessment, on a fracture mechanics basis, introduces factors of interest directly to the forging producers. The state of the art review of current forging equipment by Kramarow is also of great interest to forging producers and users alike by indicating the limitations as well as the capabilities of the various approaches.

¹ ASTM Recommended Practice for Ultrasonic Examination of Heavy Steel Forgings (A 388-84).

² ASTM Method for Ultrasonic Inspection of Turbine and Generator Steel Rotor Forgings [A 418-77 (1982)].

³ ASTM Specification for Magnetic Particle Inspection of Large Crankshaft Forgings (A 456-83).

⁴ ASTM Recommended Practice for Ultrasonic Examination of Austenitic Steel Forgings (A 745-84).

The quality of the papers and the breadth of their contents amply justified the decision to hold the symposium and indeed indicate that it was overdue. This record of the first symposium on Steel Forgings will, both with the papers and the frank discussion, assist the industry in showing what has been attained, warn of possible troublesome aspects, and serve as a reference for further development and application.

An aspect worthy of note is that where there has been a demonstrated need, there has been astonishing development of processes and procedures, as may be seen in the accounts of the large turbine and generator rotor forgings and the nuclear reactor forgings. Conversely, where demand has been absent, understandably there has been little development. This is being demonstrated in the United States, and the domestic forging community must be on guard against becoming a follower rather than a technical leader in steel forgings.

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