

## Summary—High-Temperature Alloys Session

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The third and the last session of MiCon 78 was devoted to the high-temperature alloys.

The keynote address, "Microstructural Objectives for High Temperature Alloys in Advanced Energy Systems" was delivered by Sims of the General Electric Co. Sims reviews a few advanced energy systems, in a general way, for those who are not involved in such developments. Then he addresses himself to the question, What role will superalloys play in these energy systems? He identifies potential applications and problems for superalloys and discusses the conditions that must be withstood, properties that will be required, and then discusses the ideal microstructures that one may find.

The advanced energy systems covered by Sims include coal liquifaction, coal gasification and pressurized fluid beds, and nuclear systems including liquid metal fast breeder reactors (LMFBR) and high-temperature gas reactors (HTGR). Sims discusses each of these energy systems individually and describes the major categories or superalloy *families* that will find applications therein.

Sims correlates these families or categories of materials pictorially and identifies the *power system*, draws out from these the major *critical system components*, leads to the *superalloy family* that might be used and then specifies *alloy composition examples*.

In keeping with the theme of the conference, Sims identifies ideal microstructures for superalloys utilizing the various *families/categories* as the basis for specific alloy microstructural examples.

The next three papers following the keynote address dealt with conventionally produced superalloys—melting, forging and processing, and the physical metallurgy. Emphasis again was on optimization of properties via microstructural control.

Lherbier of Universal Cyclops Specialty Steel Division points out through several examples the overriding importance of melting and casting a high quality starting material in his paper on "Melting of Superalloys."

Melting of superalloys is the initial, and perhaps the most important, step in the production of materials used in critical high-temperature applications. Increasing demands for high quality superalloys with spe-

cific requirements dictate various combinations of primary melting, refining, and secondary remelting operations.

Various combinations of melting processes can be used to obtain a desired chemistry not only in terms of the primary elements, but also for residual and tramp elements. Product forms frequently dictate a combination of melting processes that give importance to the shape of the ingot. Additionally, it is frequently important to choose melting combinations that achieve ingot structure control for optimum primary phase distribution, cleanliness or hot workability, or all.

Lherbier describes the various melting techniques: VOD, AOD, VAR, ESR, EBR, VIM and EBM, and shows how the development of these melting techniques has resulted in cost effective methods of producing high quality superalloys. He concludes that the choice of a melting sequence for the production of superalloys is dependent upon the quality and cost of the final product. He emphasizes that no amount of highly sophisticated hot or cold work, heat treatment, etc., can produce today's required quality level without a proper composition or structure in the cast ingot.

"Physical Metallurgy and Effects of Process Variables on Microstructure of Wrought Superalloys" was given by Muzyka of Carpenter Technology Corporation. Utilizing nickel-, nickel-iron, and iron-base superalloys with an austenitic matrix as examples, Muzyka shows how the property goals in these alloys, for various applications, can be achieved by proper selection of process parameters with respect to phase relationships.

Muzyka first classifies the family of the so-called heat resistant alloys, and describes the effect of each individual alloying element and presents a concise review of physical metallurgy. These will be found to be very useful by a design engineer who is not quite involved in development of these systems.

Muzyka describes how an excellent combination of tensile and creep rupture properties was accomplished by varying the forging reduction, temperature, and solution heat treatment. The phases responsible for the property latitude capability provided by *structure control* are described for the families of superalloys. The phase solvus temperatures are correlated with the alloying elements.

Muzyka then goes on to enumerate a series of steps that can be applied to any processing of superalloys, and shows the beneficial results obtained by application of the same in a number of superalloys, for example, Pyromet CTX-1, Alloy 706, etc. To keep the superalloy metallurgist honest, Muzyka also describes how structure control can be disadvantageous.

Various other thermomechanical processes associated with structure

control are described with a brief discussion of physical metallurgy of powder superalloys.

Optimization of microstructure and concomitant properties of this important family of alloys via thermomechanical processes is described in the concluding paper in the morning session, "Forging and Processing of High-Temperature Alloys" by DeRidder and Koch of Ladish Co. In their paper, DeRidder and Koch describe how the performance upgrading of superalloys can be achieved via analysis of the microstructure, as affected by various processing parameters. They review the parameters affecting the material quality and the current state of the art of forging cast material. The parameters covered include ingot characteristics, ingot conversion, closed die forging process, etc.

The authors describe the carbide severity rating system developed at Ladish for dendritic segregation or banding in the case of billets. Using metallography and microprobe analysis, DeRidder and Koch show how thermal homogenization treatments can be utilized to reduce the dendritic segregation. They point up the shortcoming of this approach, if not properly controlled, resulting in incipient melting and loss of forgeability and mechanical properties. DeRidder and Koch further describe the ingot conversion practice in terms of an intermediate thermomechanical step in obtaining the best possible microstructure, before the metal is committed to a sequence of final closed die forging. They discuss the three important parameters, that of temperature, percent reduction, and the strain rate, associated with the closed die processing of superalloys.

In the last few years, there has been a thrust toward development of powder metallurgy (P/M) technique to process superalloys for improved properties and cost advantage through near net shape approaches. Bartos of the General Electric Co. presents an excellent review of this aspect of superalloy metallurgy in his paper "Review of Superalloy Powder Metallurgy Processing for Aircraft Gas Turbine Applications."

The high costs of processing today's high-strength superalloys, such as René 95, combined with the spiraling cost of raw materials, have shifted the emphasis trends in materials technology. The transition has been from technologies to maximize high performance at minimum engine weight to concerted efforts on increased reliability and cost improvement. The inherent forging difficulties associated with cast and wrought René 95 provided the impetus for the cost reduction programs.

Using René 95 as an illustration, Bartos describes how the development and application of advanced P/M technology provided the significant breakthrough in reducing the finish part costs. Various processing techniques, hot die forging, hot isostatic pressing (HIP), and forge and hipping as related to P/M are discussed. Advances made in as-HIP P/M technology are illustrated by cost savings achieved in manufacture of complex jet

engine shaft components. The input material savings inherent in the configurational flexibility of P/M processing, combined with elimination of many fabrication steps, have culminated in as much as 80 percent cost reduction in some components.

Bartos also describes some of the potential problem areas associated with P/M, namely, defects in form of porosity and foreign particulates. These problem areas pose some unique quality control challenges to the superalloy metallurgist.

The last three papers were devoted to application of these materials.

Larson and Jenkins of Eaton Corporation review a few applications of nickel- and cobalt-base superalloys in "Application of Superalloys in Internal Combustion Engine Exhaust Valves." The authors show how these materials have played a significant role in the successful design of the exhaust valves to meet durability objectives.

Larson and Jenkins describe the two basic types of reciprocating engines that use poppet type exhaust valves. Exhaust valves, their design parameters, and metallurgical characteristics of high-temperature valve head materials are discussed in detail.

The authors point up that while most of these alloys were originally adapted from other applications, such as aerospace industry, their chemical makeup, heat treatments, and subsequent microstructural requirements have usually been modified to meet the specific needs of valve applications. To illustrate the factors governing the selection of appropriate alloys, Larson and Jenkins discuss four case studies in which tendency towards failure was eliminated by application of one of the superalloys. They conclude their paper by listing the future development opportunities for a superalloy metallurgist.

Deye and Coutts of AiResearch Mfg. Co. and Wyman-Gordon Co., respectively, collaborated on a paper "Super Waspaloy Microstructure and Properties." Super Waspaloy is a compositional (lower carbon and higher titanium plus aluminum) and processing derivative of the widely-used nickel-base alloy, Waspaloy.

The new alloy evolved from the processing work carried out by one of the authors (Coutts) in which the effect of lower forging temperature on the phase equilibria and properties of Waspaloy was studied.

Deye and Coutts compare the tensile, low cycle fatigue, and creep rupture properties of Super Waspaloy forgings with the same of Waspaloy. They further discuss the microstructural differences. The authors show that the mechanical properties can be correlated with the physical metallurgy of the alloy and, as a result, the microstructure can be used as an effective quality control check.

Mankins and Wenschhof of Huntington Alloys, Inc. presented a paper on "Microstructure and Mechanical Properties of INCOLOY Alloy 800 After 14 Years of Service as a Catalyst Tube in a Steam-Methane

Reformer." The catalyst tube was removed for examination after 14 years of satisfactory service and the authors catalog the fine microstructural changes that took place during service in the temperature range of 540 to 815°C (1000 to 1500°F).

Additionally, room temperature tensile and stress rupture properties were carried out and correlated with the fine structure. Strength increase without any adverse ductility effect is attributed to precipitation of  $\text{Cr}_{23}\text{C}_6$ . Small quantity of discrete, blocky particles of sigma phase found in one section of the tube was ascertained to be innocuous.

The application papers, although limited in nature, since they dealt with specific alloys, did contribute to the general theme of the conference. The authors clearly showed that by utilizing the microstructural control, optimum properties of a material can be accomplished.

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