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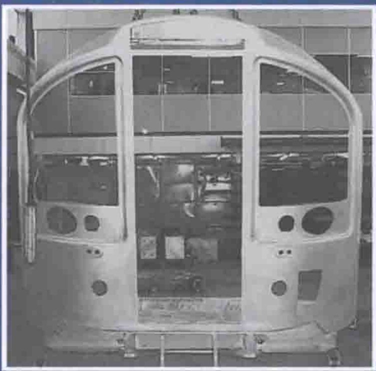

Superplastic forming of advanced metallic materials

Methods and applications

Edited by Gillo Giuliano

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Preface

Some metals, characterized by a fine and stable grain size when deformed under specific conditions of temperature and strain-rate, show an exceptional ductility known as superplasticity.

In superplastic sheet forming, those conditions are associated with uniform strains and very low flow stresses, which simplify the die's design, obtained through gas pressure

The elevated ductility of superplastic metals is useful for manufacturing products of complex forms in one operation, thereby eliminating unnecessary joints and rivets. Other benefits of superplastic forming include the reduction of residual stresses, the absence of springback, and the ability to form near net-shape parts that reduces machining costs and material waste. Because superplastic metals are light materials, superplastic forming helps to reduce the weight and the cost of the parts that they may replace. Therefore, superplastic metals can be of interest to the aerospace and transport industries, and in the fields of architecture, medicine and communications.

Relevant scientific activity has been intensely documented, and various specific conferences were promoted in order to include all the aspects of this technique: behaviour of the materials, tribology, tool design, modelling, etc.

This book aims to provide a neat and modernized synthesis of the various aspects of superplastic sheet metal forming. It is subdivided into three parts: methods, modelling and applications. In Part I, we introduce the types of metals and the mechanisms of superplasticity; the treatments that are used for refining the grain size; the equipment and procedures used for the characterization test; the types of lubrication; and the processes and equipment used for superplastic forming and for joining similar and dissimilar high-temperature metal materials.

Part II discusses the benefits and the limits of the mathematical and numerical modelling of the superplastic forming processes. Accurate constitutive equations and models for predicting instability are given in order to show the behaviour of the materials during the superplastic forming process. Finally, in Part III, the main superplastic metals of industrial interest are discussed, and some applications of superplastic forming are illustrated.

The aim of this book is to make available to engineers, researchers and students a useful means of consultation for their various roles. I thank all of the authors for their precious contributions, and all the members of the publishing team for their professionalism and patience.

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Contents

Part I

Superplastic forming methods

1
Metals for superplastic forming

N. RIDLEY, University of Manchester, UK

Abstract: This chapter deals with the requirements for superplastic behaviour and its characteristics, and outlines its potential as the basis of a commercially important shaping process. Historical aspects of the subject are dealt with. The different types of superplastic metallic materials are outlined, general methods for producing fine grain structures are considered, and specific methods for developing fine grain microstructures in commercially significant alloys are described. Observations of high strain rate superplasticity are reported and several procedures for producing ultrafine grain sizes using severe plastic deformation procedures are described. The final section deals with mechanisms of superplastic flow.

Key words: strain rate sensitivity of flow stress (*m* value), superplastic alloys, grain refinement, severe plastic deformation, mechanisms of superplastic flow.

1.1 Introduction

Superplastic (SP) materials are polycrystalline solids which have the ability to undergo exceptionally large tensile strains prior to failure, when they are deformed under a limited range of conditions (Fig. 1.1). In uniaxial tension, elongations in excess of ~200% are usually indicative of superplasticity, although Langdon[1] has proposed that this figure should be nearer 400%. However, it should be noted that elongation is influenced by specimen geometry and that the occurrence of cavitation during SP flow may lead to premature failure. Nevertheless, numerous metallic materials can show elongations of 500–1000% or more, while Higashi[2] has reported an elongation of ~8000% for an aluminium bronze. Tensile strains typical of superplasticty are shown in Fig. 1.1.

This behaviour is related to the observation that the flow stress of a SP material is very sensitive to the rate of deformation. A characteristic equation which is

Undeformed

$1.2 \times 10^{-4}\ s^{-1}$

$2.4 \times 10^{-4}\ s^{-1}$

1.1 SP titanium alloy (IMI550) showing high elongations.

often used to describe SP deformation, at least over a limited range of strain rates, can be written:

$$\sigma = k\dot{\varepsilon}^m \qquad [1.1]$$

where σ is the flow stress, k is a constant, $\dot{\varepsilon}$ is strain rate and m is the strain rate sensitivity of flow stress. A material is normally considered to be SP when it has an m value ≥ 0.3 although for many metallic materials m is in the range 0.4–0.8. During tensile deformation necks, which tend to form, lead to a local rise in strain rate, and to a sharp increase in the flow stress required to sustain plastic flow, i.e. strain rate hardening occurs within the necked region. Hence, high m confers a resistance to neck propagation and results in the high tensile strains characteristic of SP materials.

Superplasticity is a characteristic of materials which can be processed to develop a fine stable grain size, usually between 5–15 μm, when they are deformed at relatively slow strain rates normally in the range $10^{-4}\,s^{-1}$–$10^{-2}\,s^{-1}$, at temperatures $\geq 0.5\ T_m$, where T_m is the melting point in degrees Kelvin. These deformation conditions are associated with low flow stresses, generally <10 MPa and this, combined with the relatively high uniformity of plastic flow, has led to increasing commercial interest in superplastic forming (SPF).

SPF is a process whereby metallic materials in fine grained sheet form are gas pressure bulged into dies at elevated temperatures to give commercially useful products, often complex in shape, with high added value. These find a wide range of applications in aerospace, road and rail transport, architecture, and in the medical and communication fields. However, as the high value of m required to minimise differential thinning during forming is achieved at relatively slow strain rates, SPF is a slow process compared with conventional forming procedures.

Advantages of SPF are that it is a net shape forming process, it can lead to considerable savings in costs when a complex component which is normally built up of several parts can be formed as a single part, multiple parts can be produced in one operation, there is little spring back, and only one major tool is required. However, while a vast number of metallic materials have been shown to exhibit SP behaviour, most commercial SPF is concerned primarily with a relatively small number of Al and Ti alloys, although there is a developing interest in Mg alloys. There is also some commercial activity in the SPF of microduplex (α/γ) stainless steels, Ni-based alloys (e.g. IN738) and Zn–Al eutectoid.

1.2 Historical aspects of superplasticity

The first recorded laboratory observation of what was almost certainly SP deformation was published in 1912 by Bengough[3] who obtained an unusually high tensile elongation of 163% in 'complex' brass deformed at 700°C. There were further reports of SP behaviour in the early part of the twentieth century