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A Review On Superplastic Behaviour In Light Alloys

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Abstact

Superplasticity is a term used to indicate the exceptional ductility that certain materials can exhibit when deformed under proper conditions. Materials with a fine grain size, usually less than 10 μm, show superplasticity when they are deformed within the strain rate range of 10^{-5} to 10^{-3} sec^{-1} at temperatures greater than 0.5 T_m, where T_m is the melting point in Kelvin. The Superplastic Forming manufacturing process usually consists of heating the material to about half its absolute melting temperature and then slowly blowing it into the die of the required shape. Extremely thin and strong components can be formed using this technique.

Key words: Superplasticity, grain size, alloys

1. Introduction

Superplastic materials are polycrystalline solids which have the ability to undergo large uniform strains prior to failure [1]. The schematic sketch of the Superplastic deformation of a tensile specimen after undergoing tensile test is as shown in Fig 1.

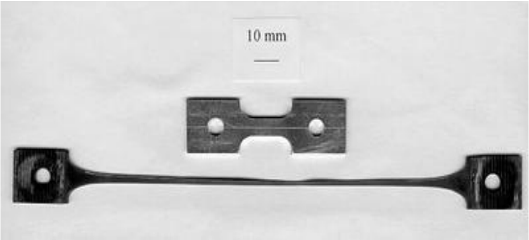

Fig 1: Schematic sketch indicating superplastic deformation

Thus, the superplastic term is most often related to the ductile tensile behavior of the materials, however superplastic deformation has the characteristic of easy deformation under low pressure and compressed deformation characteristic are also described as superplastic. Superplastic materials exhibit very high tensile elongation, typically 500% or more, in a particular range of temperature and strain rate [2]. Such superplasticity in a material depends highly on the strain rate and occurs only in a narrow range of strain rate with an optimum value that is unique to each material: usually very low, such as 10^{-3} - 10^{-5} sec^{-1}.

Superplasticity in material arises from a high resistance to plastic instability during deformation, which leads to extremely large elongation (several hundred to several thousand percent), as shown in Table 1 [3]. Internal stress induced superplasticity is developed due to internal strain produced by thermal expansion mismatch between two phases [4] by phase transformation or by expansion anisotropy. However, The process could not be developed to a sufficiently controllable stage for commercial use.

There are several different types of Superplasticity in terms of the microstructure mechanisms and deformation conditions, including the following.

(i) Micro Grain Superplasticity
(ii) Transformation Superplasticity
(iii) Internal Stress Superplasticity

At this time, only the micro gain Superplasticity is of importance in the fabrication of parts and the discussion will be limited to this type. For micro grain superplasticity, the high ductilities are observed only under certain conditions and the basic requirements for this type of super plasticity are:

- Very fine grain size material (of the order of 10μm)
- Relatively high temperature (Greater than about one-half the absolute melting point)
- A controlled strain rate (usually 0.0001 to 0.01 sec^{-1})

2. Prerequisites for Micrograin Superplasticity

2.1. Grain Size

Grain size is probably the single most important parameter for developing micrograin superplasticity. An ultrafine grain size is the most important microstructural attribute of superplastic alloy. The finer, the grain size, more are the grain boundaries. Since grain boundary structure is random and therefore behaves like viscous material, superplasticity develops in fine grain material. The apparent viscosity of superplastic Materials have been determined to be 10^4 – 10^9 poises [5] (for hot glass the value is 10^7). When the grain size is finer, the flow stress is lower, the strain rate sensitivity 'm' becomes higher and the total tensile elongation is greater [6]. A finer grain size also tends to increase the strain rate range at which the superplastic region exists [7]. The dependence of stress on grain size can be described by the following relationship

2.2. Temperature

It is generally agreed that the temperature for superplastic deformation must be in excess of about 0.5 Tm, where Tm is the absolute melting point. The need for the elevated temperature is to provide the diffusion mechanism necessary for permitting the superplastic deformation to proceed. Below 0.3Tm, the diffusion kinetics becomes too sluggish [8]. The maximum deformation temperature is, however, limited by the consideration of grain coarsening or the phase transformation temperature. For high strength precipitation hardening A1-alloys like 7475 the optimum superplastic deformation temperature has been reported as 789K, which is slightly above its solutionising temperature (755K). On the other hand, for A1-Li alloy the optimum superplastic temperature (773-783K) was marginally below the solutionising temperature.

2.3. Strain-Rate

Fine grained superplastic materials invariably exhibit a high strain-rate sensitivity of flow stress within a certain strain-rate range, as shown in Fig.2 schematically [7], usually in the strain rate range of 10^{-4} to 10^{-2} Sec^{-1}. Superplasticity occurs in region II only, where the strain-rate sensitivity lies between 0.3 to 0.9 [9]. According to NIX, however, the value reaches a maximum of 0.5. In region I and III the strain rate sensitivity again falls to 0.2 or less for some alloys [10], and the tensile elongations are usually less than 200%.

The strain rate (ε) corresponding to maximum strain-rate sensitivity 'm' generally increases with decreasing grain size, and with increasing temperature. Obviously the increase in ε* is desirable from the standpoint of reducing forming time during practical forming. Moreover, grain coarsening is also minimum with minimum forming time.

2.4. Strain-Rate Sensitivity Index 'm'

Superplastic ductility is generally found to be related to the strain rate sensitivity exponent 'm' where

$$m = (\partial \ln\sigma) / (\partial \ln\varepsilon) \quad \dots 2.2$$

where, σ = flow stress ,

ε = true strain rate

The high strain rate sensitivity of a material imparts high neck resistance which in turn results large elongation. Holt has provided the following explanation [11].

By manipulating the well known equations,

$$\sigma = P/A \quad \dots 2.3$$

$$\varepsilon = -l/A\ (dA/dT) \quad \dots 2.4$$

$$\sigma = K\varepsilon^m \quad \dots 2.5$$

The following relationship can be derived.

$$dA/dT = -(P/K)^{l/m} A^{l-l/m} \quad \dots 2.6$$

Table – 1 : Summary of Superplasticity in Different Alloys [3]

Alloys	Test Temp. (°C)	Strain rate(S^{-1})	'm'	Elong(%)
Statically Recrystallized				
Al-33Cu	400-500	8.0 x 10^{-4}	0.8	400-1000
Al-4.5Zn-4.5CA	550	8.0 x 10^{-3}	0.6	600
A1-6 to 10Zn-1.0Mg-0.2Zr	550	10^{-1}	0.9	1500
A1-5.6Zn-2Mg-1.5Cu-0.2Cr	516	2.0 X 10^{-4}	0.8-0.9	800-1200
Dynamically Recrystalized				
A1-6Cu-0.5Zr	450	10^{-3}	0.3	1000
A1-6Cu-0.35Mg-	450	10^{-4}	0.3	900

0.14S1				
A1-4Cu-3LI-0.5Zr	450	5.00 X 10^{-4}	0.5	900
A1-3Cu-2LI-1Mg-0.2Zr	500	1.30 X 10^{-4}	0.4	878
Iron Base Alloys Ultra High Carbon				
Fe-(1.3-1.6C)	650	1.67 X 10^{-4}	0.5	250-1500
Fe-(2.1-2.4C)	650	1.67 X 10^{-4}	0.5	526
Alloy Steels				
Fe-0.4C-1.9Mn	727	3.34 X 10^{-4}	0.5	460
Fe-0.13C-1.1Mn	800	8.30 X 10^{-4}	--	275
Fe-0.33C-1.14Mn	900	3.34 X 10^{-4}	--	430
Fe-4Ni-3Mo-1.6Ti	900-960	8.30 X 10^{-4}	0.5-0.7	800
High Carbon Low Alloy:				
Fe-1.0C-0.5W- 0.2V-1Mn	650	1.67 X 10^{-4}	0.5	1200
Stainless Steels				
Fe-26Cr-6.5Ni	960	3.30 X 10^{-3}	0.55	1000
Fe-18.5Cr-4.9Ni- 2.8Mo	1000	8.3 X 10^{-4}	0.7	700
Ni-Base Alloys:				
Ni-Cr-Fe	1000	--	0.5	960
Inconel	--	--	0.7-0.9	250
Astrology	--	--	--	
Zn-6KP	--	--	0.4-0.6	
Ni-Mo	--	--	--	--
IN-100(PM)	--	--	--	--
IN-738(PM)	--	--	0.4	500
713LC (PM)	--	--	0.5	230
NASA TAZ-8 (PM)	--	--	--	600
MAR-M200 (PM)	1038	--	--	--
PA 101	--	--	--	--
RENE 95 (PM)	927	--	--	--
Ni-Cr-Fe	1000	--	0.5	960

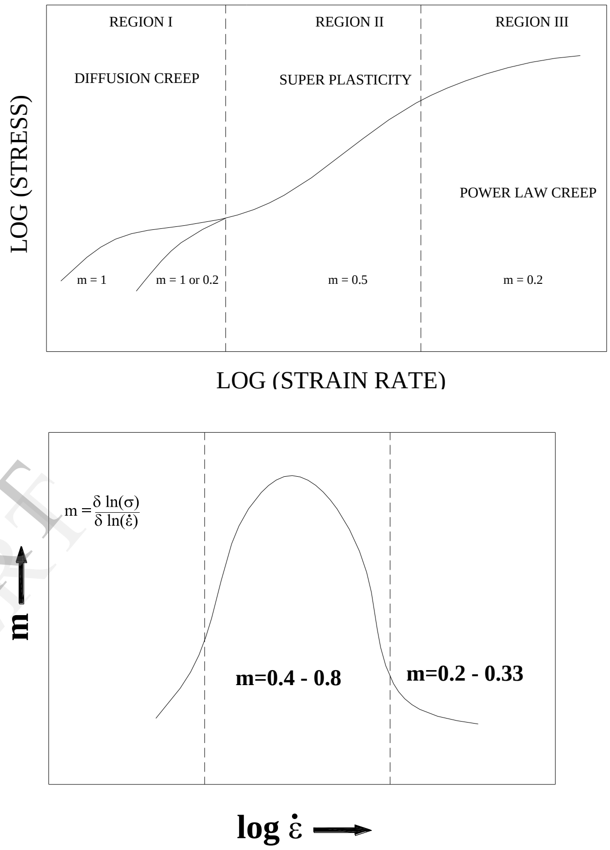

Fig. 2 : Schematic representation of Superplastic behaviour

2.5. Characteristics of superplastic metals

For a superplastic metal that is tensile tested under proper conditions of temperature, the observed ductility is seen to vary substantially with strain rate, as shown in Fig.3 for a Zinc-Aluminum eutectoid alloy. As shown, there is a maximum ductility at a specific strain rate, with significant loss in ductility as the strain is increased or decreased relative to this maximum. It is well known that the primary factor related to this behavior is the rate of change of flow stress with strain rate, usually measured and reported as ‘m’, the strain rate sensitivity exponent, is defined as;

$$m = \partial \ln\sigma / \partial \ln\dot{\varepsilon} \quad \text{----------(1)}$$

where σ is the flow stress and $\dot{\varepsilon}$ is the strain rate.

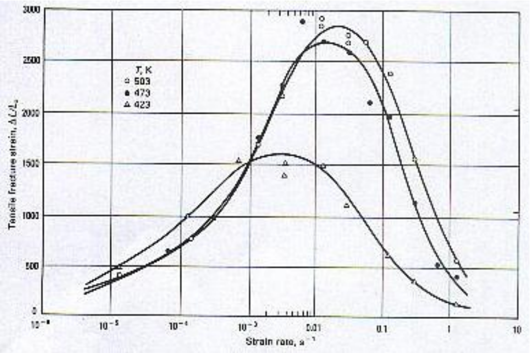

Fig:3.Tensile fracture strain versus initial strain rate for a Zn-22Al alloy having a grain size of 25μ m tested at temperatures ranging from 423 to 503 K.

Conclusions

Superplasticity in different alloys can be attributed to different parameters like grain size, temperature, strain rate and strain rate sensitivity index etc. The ability of superplasticity can be attained by different techniques which enable an alloy to form into difficult to form and complicated shapes because of its high ductility. An alloy, on attaining superplasticity can have higher ductility values even above 500%.

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