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A STUDY ON FLOW STRESS OF METAL IN SOLID-LIQUID'S COEXISTING STATE

固液共存状想における金属の変形抵抗

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1. Introduction

It is well known that flow stress of metal decreases as its temperature rises. This property is applied to various hot prastic workings. Recently, some working processes are newly being developed which include metal deformation in the temperature range over liquidus line, such as extrusion casting, ACURAD process and continuous casting in high speed. In order to study these processes it is very important to get the basic data on flow stress and flow behavior of metal in the temperature range over its liquidus line, very few of which are known.

Fom this viewpoint, the authors made compression tests using a cam-plastometer on the alloys of Pb-Sn and Al-Cu in their solid-liquid's coexisting state, and got some data on their flow stress.

2. Experimental apparatus and method

Under the test strain rate was fixed and it was about 0.2/sec.

Test pieces were made from Pb, Sn, Al of 99.9% purity and Cu of 99.99% purity. They were melted into alloys in a cruisible at about 450°C for Pb-Sn and at about 900°C for Al-Cu respectively, and each alloy was cast in a metal mold and finished into prescribed shape under a lathe. Two kinds of test pieces were used and their dimensions were 20 mm in diameter, 18 mm in height (for Pb-Sn) and 26 mm in diameter, 23.5 mm in height (for both alloys). Each end surface was finished as smooth as possible. The dimension error was within 0.05 mm for both diameter and height. The components of Pb-Sn alloy were Pb; 80.8% and Sn; 19.2%, those of Al-Cu alloy were Al; 94.3% and Cu; 5.7%.

A sub-press was used in order to keep the test piece in high temperature during the test. It was made from SUS42 (stainless steel) and its shape and dimensions were shown in Fig. 1.

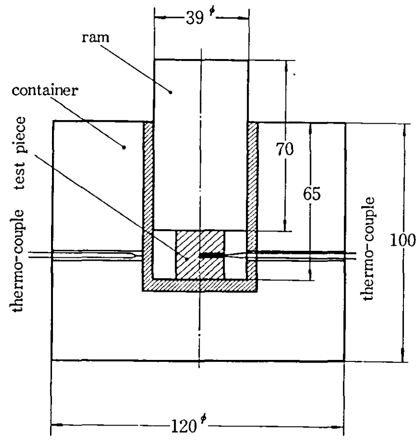

Fig. 1

The procedure of test was as follows. The test piece was set in the sub-press and heated in the electric furnace. After having come to the prescribed temperature, the sub-press and the test piece contained in it was kept at the temperature for about 20 minutes, and then they were set in the cam-plastometer and subjected to the compression test. In whole this process, temperature of the test piece was measured with a thermocouple of chromel-alumel inserted in it through a hole of 1 mm in diameter which reached its center. The electric furnace was controlled automatically according to the measured temperature of the container of sub-press.

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The temperature error of the test piece was assumed within 1°C.

During the process compression force was measured with a load cell and displacement was measured with a differential transformer.

3. Results and considerations

3.1 The relationship between temperature (T) and solid content (φ)

The solid content of tested alloy in solid-liquid's coexisting state can be got from the temperature of the test piece by using the phase diagram of the alloy. In the phase diagram shown in Fig. 2, the solid content φ of X-Y alloy containing α% for metal Y can generally be written as,

$\varphi=100(\mathrm{A}/\mathrm{B})$ (%)

Corresponding to Fig. 2,

$$\varphi=100((T_0-T)(T_M-T_S))/((T_0-T_S)(T_M-T)) \quad (1)$$

$$T_0=(1-\alpha/\beta)T_M+(\alpha/\beta)T \quad (2)$$

From the equations (1), (2) the solid content φ (%) at the temperature T is obtained.

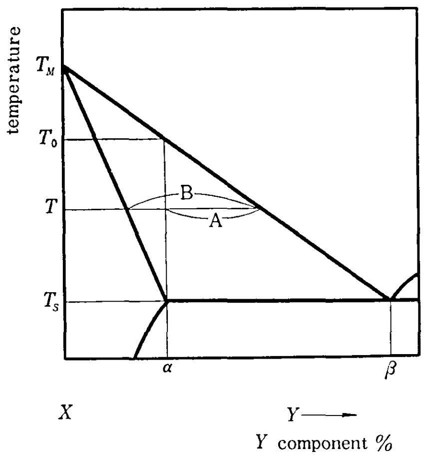

Fig. 2

3.2 Relationship between stress and strain

When it is assumed that the volume of the test piece is kept constant and it deforms into the shape of column, the following relationship between its height H and its diameter D can be obtained,

$$\pi D_0^2 H_0=\pi D^2 H,$$

where H_0 is the initial height and D is the initial diameter.

Then the mean compression stress,

$$\sigma=4P/(\pi D^2)=(4/\pi)(P/D_0^2)(H/H_0),$$

where P is the compression force.

Here strain means logarithmic strain and is defined as $\bar{\varepsilon}=\ln(H/H)$.

3.3 Results on Pb-Sn alloy

Some typical examples of compression force-stroke curves are shown in Fig. 3, where strain rate is about 0.2/sec. As shown in it, in case of Pb-Sn alloy, test pieces failure at the strain range of 3~5% and suddenly flow stress decreases. This tendency is not affected by the solid content.

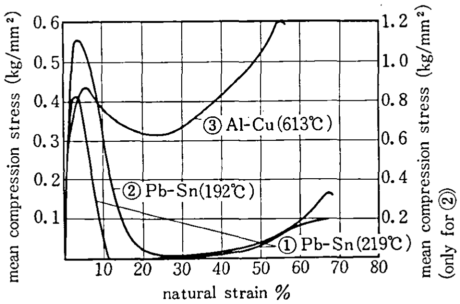

Fig. 3

Fig. 4.1 shows the equilibrium phase diagram of Pb-Sn alloy and Fig. 4.2 shows the relation-

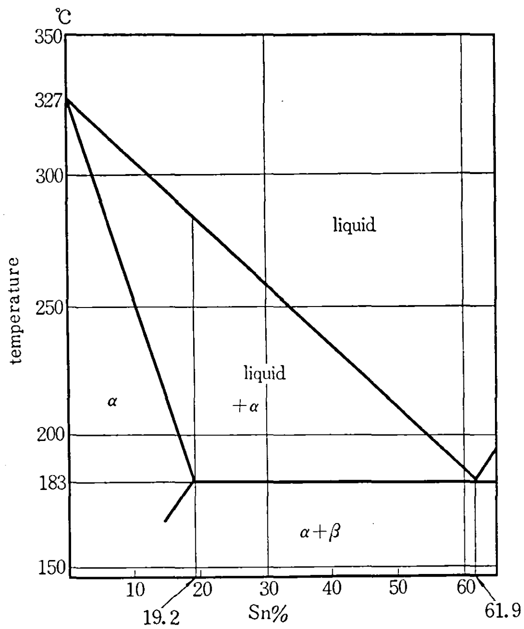

Fig. 4-1

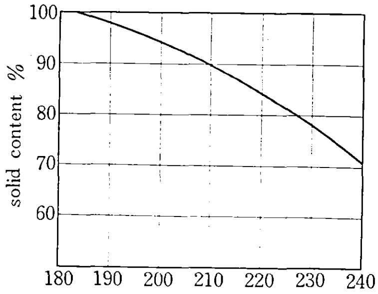

Fig. 4-2

ship between temperature and solid content for the alloy. Fig. 5 shows the relationship between solid content and flow stress corresponding to 4 % strain. The flow stress in Fig. 5 was obtained in the test about the specimens of 20×18. Fig. 6 shows the same results about the specimens of 23.5×20.

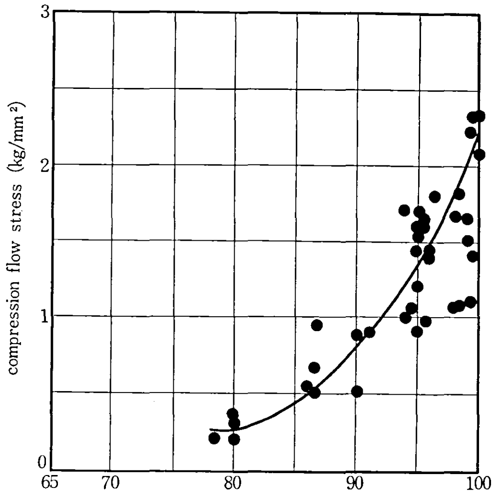

Fig. 5

The flow stress of the alloy with 100% solid content that is on the solidus line is about a half of that at room temperature (4.5 kg/mm at 4 % strain). Moreover, the flow stress decreases as much as 1/5 of that of 100% solid content alloy according to the decrease in the solid content from 100% to 80%.

3.4 Result on Al-Cu alloy

Fig. 7 shows the relationship between flow stress corresponding to 4 % strain and solid content. From this result it can be known that the

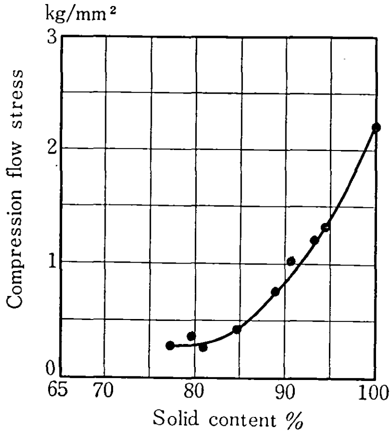

Fig. 6

flow stress decreases to about 1/4 for the change in solid content from 100% to 75%, and that it decreases no more for farther decrease of solid content. Fig. 8 shows the change in flow stress for wider range of temperature, where the flow stress at melting point (548°C) corresponds that of 100% solid content in Fig. 7.

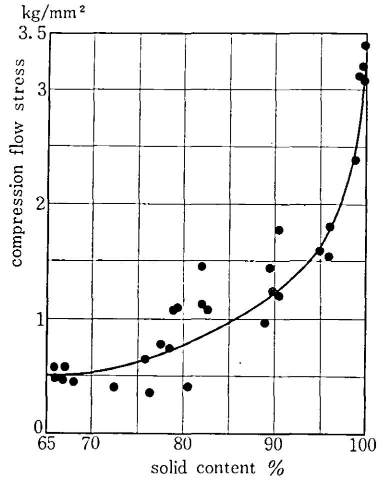

Fig. 7

3.5 Comparison between Pb-Sn and Al-Cu

In regard to the flow stress of these two alloys in the solid-liquid's coexisting state, following points may be known.

1) According to decrease of solid content from 100% to 75～80% in temperature range over the melting point, the flow stress decreases to 1/4～1/5 of that at melting point.
2) Over the melting point, both alloys are apt

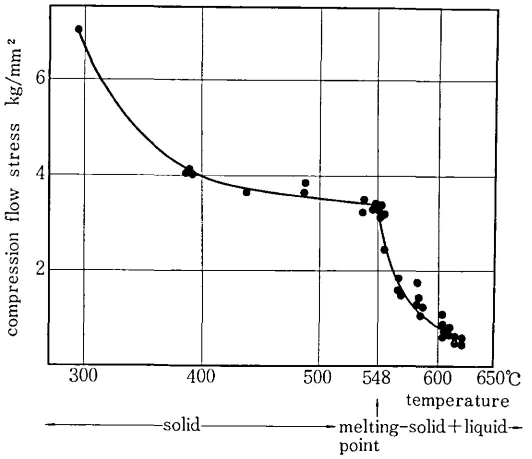

Fig. 8

to failure in these deformation processes. (Ref. Fig. 3). Pb-Sn alloy shows the sharper tendency than Al-Cu.

4. Summary

Following results were obtained from the uniaxial compression test on Pb-Sn and Al-Cu alloys in solid-liquid's coexisting state.

1) The relationship between flow stress and solid content has been clarified.
2) According to decrease of solid content from 100% to 75~80%, the flow stress decreases to 1/4~1/5.
3) The alloys in solid-liquid's coexisting state failure in the strain range of 3~10% in uniaxial deformation.

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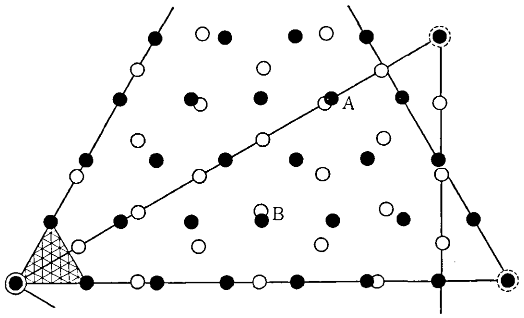

Fig. 2　Σ48.5 Quasi-coincidence relationship

Ashby[9] らの実験は主にこれを調べている．この粒界は最稠密な〔1$\bar{1}$0〕$_A$ と二番目に稠密な〔2$\bar{1}\bar{1}$〕$_B$ が平行になったため生じた準規則粒界と考えられるが，写真で示したように〔7$\bar{7}$0〕$_A$ と〔8$\bar{4}\bar{4}$〕$_B$ との近似的一致が原因となって，同様な配列がひんぱんにくりかえされていることがわかる．Fig. 2 はこれの対応関係図で図中左端に示したのがバーガースベクトル格子である．単位ベクトル $b^{GBD}=\frac{a}{49}$〔8$\bar{4}\bar{4}$〕$_A$ (図中A) は大きな粒界階段をもつためあまりみられず，かわりに $b^{GBD}=\frac{a}{8}$〔1$\bar{1}$0〕$_A$ が配列している．写真中央左側にある粒界階段は，Fig. 2 *P* の粒界転位 $b=\frac{a}{49}$〔$\bar{4}\bar{4}$8〕$_A$ のものである．タングステンのイオン電界顕微鏡観察でこれに由来する準対応粒界が実際に観察された[5]．

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参 考 文 献

1) R. W. Balluffi and T. Y. Tan: Scripta Met. **6**, 1033 (1972)
2) P. H. Pumph ey: Scripta Met. **6**, 107 (1972)
3) B. Loberg and H. Norden: Acta Met. **21**, 213 (1973)
4) J. Levy: Phys. Stat. Sol. **31**, 193 (1969)
5) Y. Ishida and D. A. Smith: (to appear in Scripta Met.)
6) M. J. Weins and J. J. Weins: Phil. Mag. **26**, 885 (1972)
7) 石田：生産研究 **25**, 203 (1973)
8) Y. Ishida and M. McLean: Phil. Mag. **27**, 1125 (1973)
9) M. F. Ashby: Surface Science **31**, 498 (1972)