Mechanical Characteristics of a Ductile Material

—On Creep Recovery of ASARCO 281—

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1. Introduction

ASARCO 281 is a kind of very soft alloy which has been manufactured from American Smelting And Refining Company and been used in wide area as an easy molding material at low melting point. Besides this is a ductile-type material not seen in such an iron alloy. This kind of material will be needed high energy for its plastic deformation in order to have latent crack growth.[1] For this reason, it is necessary to increase an applied force for developing the cracks. Creep is a physical phenomenon participating in one side phase of this character.

In general, steel and light alloy show a large creep only at high temperature (over 250°C). However, ASARCO 281 showed a large deformation under a compressive stress, and ductile flow like a soft solid was observed even at room temperature and in a short time. It becomes a matter of great concern to clarify the creep characteristics,[2),3)] experiments were made on ASARCO 281 cylindrical specimens with an uniaxial compressive loading. A large amount of "recovery" of plastic strain was observed in tests but there was no sudden change in plastic strain. Several laboratory mechanical behavior of ASARCO 281 conducted eqautions of creep (which means here negative creep, but it will be named simply creep in subsequent sections) strain time relations. This is a preliminary report on an experimental study of elastic after-effect of a ductile-type material.

2. Specimens and Test Procedure

Specimens are 2 inches in diameter and 4 inches long, and right angle surface. The compositon of this alloy is 58% bismus and 42% tin. The melting point is 281° F (138°C). They are tested by a conventional compression test through an ordinary testing machine (Riehle 380,000 lbs) with a seat having hardened platens. The testing machine measures the sum of the hydraulic load on the specimen and also draws the longitudinal strain that is picked up by L. V. D. T. system (electric gauge) on the data sheet. Five loadings and unloadings are repeated. After final unloading, stress is released and immediately creep recovery is measured in each time interval. Selected stress level is mainly in the ranges of 0 to 2,500 lbs/in^2 and 0 to 5,000 lbs/in^2. These tests were carried out at room temperature (22°C) and in a short time (≈60 minutes).

3. Analysis of Experimental Result and Discussion

Recovered strain was calibrated from the testing machine record, and creep recovery was also calculated from the load-strain chart after each time interval.

In this case, if the total strain is assumed as $\varepsilon = \varepsilon_p + \varepsilon_e$, in which ε_P is total plastic strain and ε_e is elastic strain, the total plastic strain is represented as follows:

$$\varepsilon_p = \varepsilon_{p1} + \varepsilon_{p2} + \varepsilon_{p3} + \varepsilon_{p4} + \varepsilon_{p5} \qquad (1)$$

Similarly, recovered strain is expressed as:

$$\Delta\varepsilon = \sum_j \Delta\varepsilon_j \qquad (2)$$

Now, we define here m-th creep recovery as:

$$Rc_{(m)} = \frac{\sum_{j=1}^{m} \Delta\varepsilon_j}{\sum_{i=1}^{5} \varepsilon_{pi}} \qquad (3)$$

In Fig. 1, Rc is indicated in per cent (%). ε_p is a constant in each test, $\Delta\varepsilon$ is a variable with respect to time. One can see the two groups of creep recovery-time relations. In this figure, the upper one consists of small total strain and slight steep slope lines, the other is made up with some gentle slope lines.

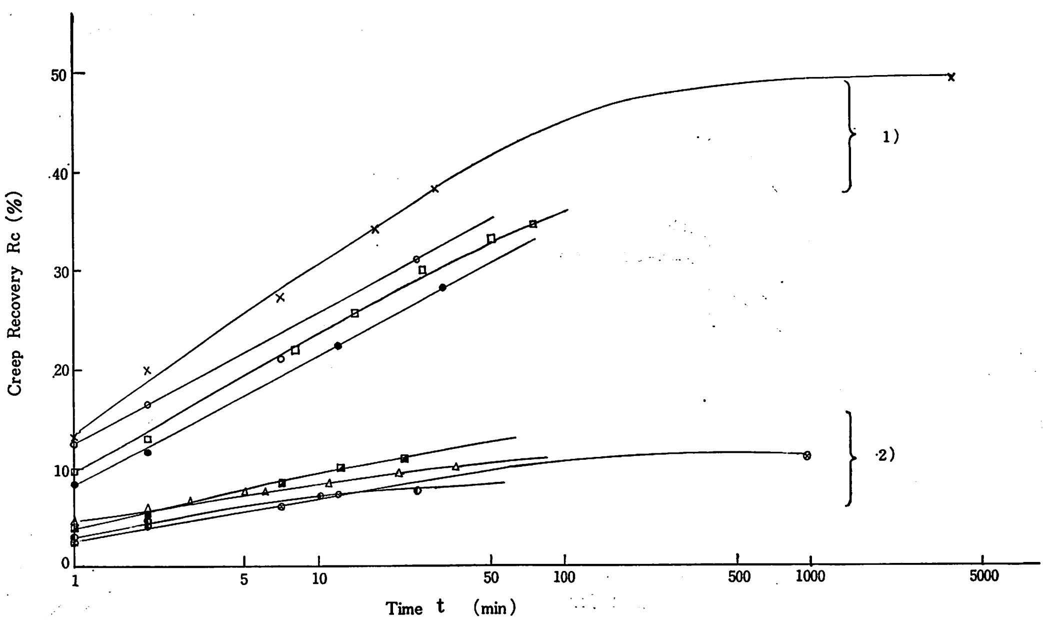

Fig. 1 Creep Recovery Time Relationships

The main reason of tis tendency is based on how fast plastic strain is recovered duringnormal stress (σ) is released. This will be explained later.

As is seen in the figure, simple experimental formulae were obtained relating "Rc" and time "t" (in minute) for two groups.

$$Rc = \alpha + \beta \log t \qquad (4)$$

α and β are material constants, these were found to be:

$\alpha_{1)} = 10.9$, $\alpha_{2)} = 3.60$, $\beta_{1)} = 0.308$, $\beta_{2)} = 0.298$.

1) and 2) are group suffix. Thus the eq. (4) becomes

$$\left.\begin{array}{l} Rc_{1)} = 10.9 + 0.308 \log t \\ Rc_{2)} = 3.60 + 0.298 \log t \end{array}\right\} \qquad (5)$$

If one considers after 100 minutes, the relation may be assumed in the following general form, instead of eq. (4), as:

$$Rc = \alpha + \beta \log t + \gamma t^{\delta} \qquad (6)$$

where γ and δ are material constants to be determined from a chart. More long period of time tests appear to be necessary to determine γ and δ.

Plastic strain after t-minute is given by

$$\varepsilon_p = \frac{\Delta\varepsilon}{\alpha + \beta \log t} \qquad (7)$$

If recovered strain is very large, eq. (7) becomes

$$\varepsilon_p \cong \Delta\varepsilon \quad \text{or} \quad \varepsilon_p \cong \varepsilon_e \qquad (8)$$

but most cases, $\varepsilon_p \gg \Delta\varepsilon$.

To a different stress level, an interesting tendency appeared as shown in Fig. 2 which describes the relation of ε_p and loading cycle (N). In the figure, (1) and (2) are stress levels in the ranges of approximate 0 to 2,500 lbs/in^2 and to 5,000 lbs/in^2. From the figure, the strain ratio between two stress levels is changing in exponential

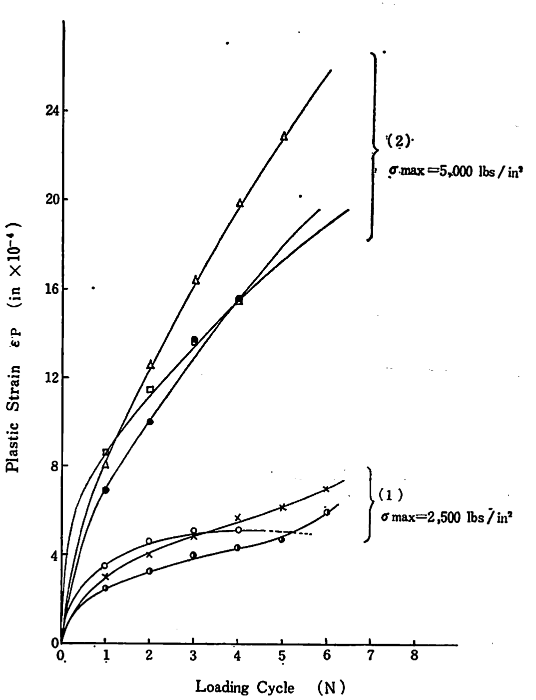

Fig. 2 Plastic Strain-Loading Cycle Curves

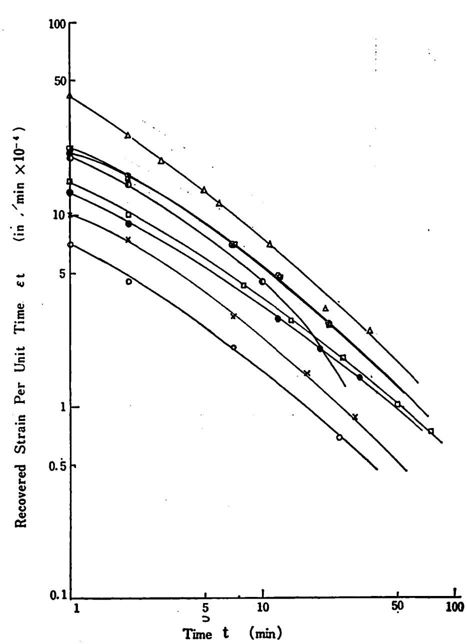

Fig. 3 Time-Dependent Plastic Strain

in proportion as n increases. With the limit of this experiment, the diagram indicates the relation which may be expected by a simple equation such as

$$K = f\,(W)\,N^{(n_1-n_2)} \qquad (n_1>n_2) \qquad (9)$$

where K is a magnification between large deformation and small deformation in respecting the stress levels and loading cycles, W is a function of K and depending upon weight ratio, n_1 and n_2 are constants depending upon whether the deformation is large or small. To determine the ratio of the deformation, the eq.(9) might be solved experimentally.

Consider the variation of rate of recovered strain (ε_t). It depends highly on time especially when a large creep recovered at the beginning of relaxation of stress. The relation can be expressed as:

$$\log \varepsilon_t = \log \mu - k \log t \qquad (10)$$

where μ and k are material constants. The experimental results which were obtained in the way described above are shown in Fig. 3. In this case, μ average and k are solved as 18.75 and 0.675, thus

$$\varepsilon_t \fallingdotseq \frac{18.75}{\sqrt[3]{t^2}} \qquad (11)$$

By using $\varepsilon_t = \Delta\varepsilon/t$, eq. (10) becomes to the following general form.

$$\Delta\varepsilon = \frac{\mu}{t^{k-1}} \qquad (12)$$

From eq. (7) and eq. (12), recovered strain may be expressed in the form of

$$\varepsilon_p = \{\mu\, t^{-(k-1)}\}\,(\alpha + \beta \log t)^{-1} \qquad (13)$$

According to this equation, we can estimate appropriate creep recovery if we take proper μ, k, α and β in each case. The approximations of plastic strains may be made depending upon whether the time is short or long. If a material has a large deformation, the plastic strain recovery rate will be fast. This also tells us that at low stress and minimum time, a small creep recovery will be raised. It seems to be quite all right to consider that it is hard to deform the material by a small creep recovery. Therefore, Rc can be changed continiously by operating the testing machine at any time. In this experiment, Rc is devided into two stages concerning ε_t/σ which is an index of whether the matereial deformation is hard or easy, because ε_t/σ eqauls to $\varepsilon_p/\sigma\cdot t$ and $1/E\cdot t$ (compliance per unit time). It is to say that the lower stage is hard for deformation in Fig. 4,and which suggests that the two stages are based roughly on following tentative boundaries.

$$\left.\begin{array}{l}\text{To upper stage, } Rc > 25\% \;;\; \varepsilon_t/\sigma < 2.0 \\ \text{To lower stage, } Rc < 15\% \;;\; \varepsilon_t/\sigma > 2.0\end{array}\right\} \qquad (14)$$

From above analysis, Rc can be rewritten in the following form.

$$Rc = \frac{\mu}{t^{(k-1)}\,\varepsilon_p} \qquad (15)$$

creep recovery rate is given by differentiating the eq. (15).

$$\dot{R}c = \frac{d\,Rc}{d\,t} = \frac{\beta}{t} \qquad (16)$$

Plastic strain rate is also expressed as :

$$\dot{\varepsilon}_p = \frac{\mu \{(1-k)(\alpha+\beta \log t)-\beta\}}{t^k (\alpha + \beta \log t)^2}$$

$$= \frac{\{\mu (1-k) - \beta \cdot \varepsilon_p \cdot t^{(k-1)}\}}{\mu \quad t} \varepsilon_p \qquad (17)$$

Similarly, we find an equation of recovered strain rate as :

$$\dot{\Delta\varepsilon} = \frac{\mu}{t^{(k-1)}} (1-k) = \frac{(1-k)}{t} \Delta\varepsilon \qquad (18)$$

Combining above equations, we obtain a general equation of the following form :

$$\frac{\dot{\varepsilon}_p}{\varepsilon_p} = \frac{\dot{\Delta\varepsilon}}{\Delta\varepsilon} - \frac{\dot{R}_c}{R_c} \qquad (19)$$

Consequently, creep recovery rate is found in relating R_c, $\Delta\varepsilon$, ε_p, $\dot{\Delta\varepsilon}$ and $\dot{\varepsilon}_p$. Obiviously, the value of creep recovered rate cannot be constant, although the plastic strain will remain constant according to loading cycle in each experiment.

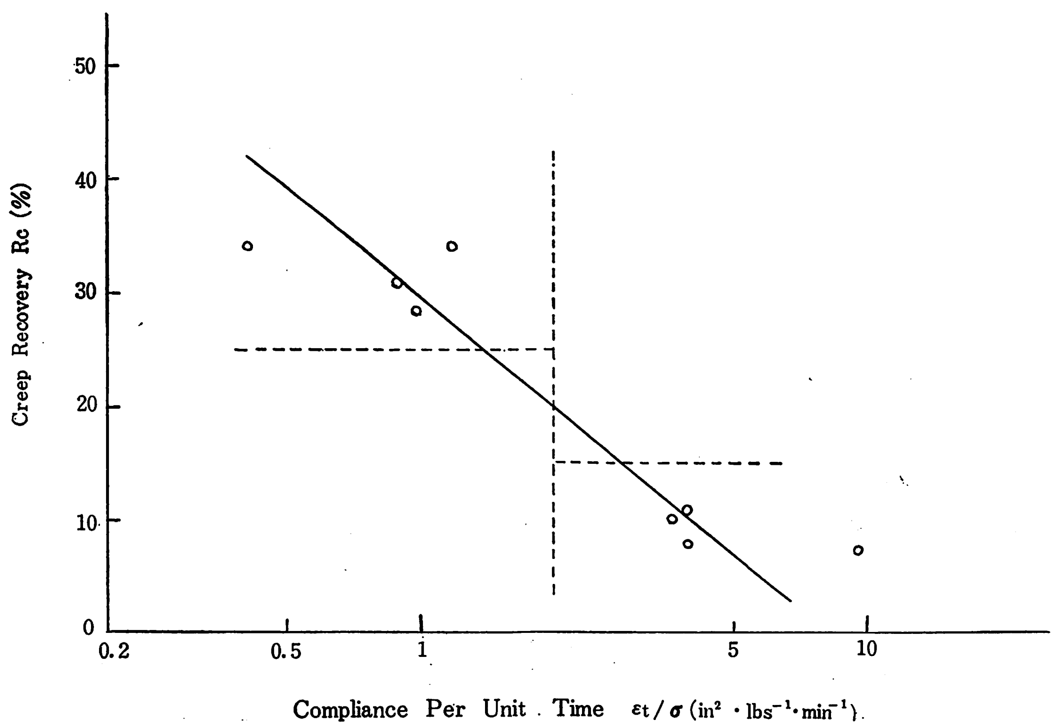

Fig. 4 Two Stages of the Deformability

A reliable conclusion cannot be drawn due to an insufficient number of experimental samples, but the investigation to ASARCO 281, as a temporary standard, indicates the possibility of the analysis of ductile-type materials.

4. Conclusions

For understanding creep,it seems necessary to explain the mechanical behavior of the material. The present investigation is essentially an exploration of this idea. This paper suggested some eqautions for creep characteristics in the case of uniaxial compressive stress. By some preliminary creep recovery experiments, it was deduced that the behavior of ASARCO 281 tested indicated approximate agreement to an ordinary elastic after-effect of organic materials even at room temperature and in a short time,although creep is strongly influenced by temperature and time. The same idea might be applied to compare with the case of tension and torsion tests or other ductiletype materials. Further research is necessary for value analysis in respect to laboratory testing for criterion for creep of long period of time and different temperatures.

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