

Improving the Relationship between Processing and Properties of Zinc Die Casting: Developments in Creep and Ageing Correlations

2011-01-1082

Published
04/12/2011

Frank E. Goodwin
International Zinc Assn.

Lothar Kallien
Aalen University of Applied Sciences

Copyright © 2011 SAE International

doi:[10.4271/2011-01-1082](https://doi.org/10.4271/2011-01-1082)

ABSTRACT

Most creep studies are conducted to determine steady state creep rate and time to failure. However, the priority for the designer is to predict the amount of total creep, being the sum of primary and secondary creep elongations, for a given service life under given loads and temperatures, for example 0.5% elongation after 3000h. An assessment of total creep behavior of industrially important zinc alloys has been conducted, and correlation/prediction curves produced. Another important property, related to creep, is stability after ageing, both for unloaded and also loaded castings. Recently developed relationships between natural and artificial ageing, and the correlation of mechanical property changes for different periods of artificial ageing with natural ageing will be presented.

Development of Improved Predictive Techniques for Zinc Alloy Creep Behavior

Use of pressure die-cast components at service temperatures up to 120°C is dependent upon the creep resistance of the alloy. Some parameters of interest to designers are the time to a given strain (e.g., time to 1% strain) and design stress to produce a given strain in a set time period (e.g., stress to produce 0.2% strain in 100,000 hours). Creep testing is, by its very nature, a slow process. Experimentalists depend upon theoretical equations and accelerated test methods utilizing multiple temperatures and stress levels to predict long-term

properties. A method based upon the kinetics of creep has been used previously for die cast-zinc alloys^{1,2}:

$$f(\epsilon) = A t \sigma^n \exp(-Q/RT) \quad (1)$$

where A is a constant which takes into account the effects of composition and structure, σ is the nominal stress, n is the stress exponent, t is the creep time, Q is the effective activation energy for creep, R is the gas constant, T is the absolute temperature of the test, and f(ϵ) an undefined function of the creep strain ϵ . When A, σ , n, Q, and T are constant, f(ϵ) represents the shape of the creep strain versus time curve. Note also that this equation reduces to the power law representation for creep behavior in the steady state region when f(ϵ) = ϵ and both sides of the equation are differentiated with respect to time³.

As Murphy, Durman, and Hill show⁴, equation (1) can be further manipulated by taking logarithms and rearranging to obtain:

$$\ln t = \ln f(\epsilon) - \ln A - n (\ln \sigma) + Q/RT \quad (2)$$

and at a constant strain:

$$\ln t = C' - n (\ln \sigma) + Q/RT \quad (3)$$

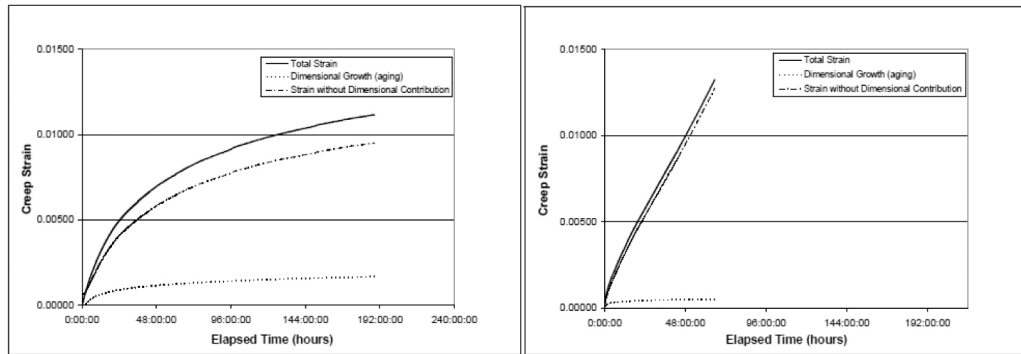


Figure 1. Total strain and contribution to strain from dimensional growth. 1a: Alloy 2 at 120 °C and 10 MPa. 1b: Alloy 5 at 120 °C and 10 MPa.

where C' is a constant which incorporates A and ϵ . Determination of the constant C' allows calculations of design stresses, for example, which will produce 1% creep strain in 100,000 hour at various temperatures. Murphy et al published an extensive study of three commercial zinc-based alloys: Alloy 3 (Zn-4%Al-0.05% Mg), ZA-8 (Zn-8%Al-1%Cu-0.03%Mg) and ZA-27 (Zn-27%Al-2%Cu-0.02% Mg)⁵. The data was found to correlate with equation (1) for $n = 3.5$ and $Q = 10$ kJ/mol. The value of the creep constant C' was tabulated for the three alloys at 0.2%, 0.5%, and 1.0% strain.

Creep Behavior of Alloys 2 and 5

The behavior of two other commercial alloys, Alloy 2 (Zn-4Al-0.03Mg-2.7Cu) and Alloy 5 (Zn-4Al-0.05Mg-1.0Cu) have been evaluated using the same methodology in industry sponsored research at the USA Department of Energy Albany Research Center. Furthermore, Alloy 2 is a copper-rich alloy with dimensional changes due to aging. The contribution of aging to the creep strain was evaluated.

The experimental procedure, using flat diecast specimens nominally 19 mm wide, 1.5 mm thick, and with a 70 mm reduced section is described elsewhere.⁵

Creep elongation versus time curves were produced for the combinations of applied stress and test temperature. The data from the null tests were used to evaluate the effect of aging on total creep strain. From the creep elongation versus time curves, steady state creep rate and times to obtain total creep elongations of 0.25, 0.5, and 1% strain were obtained. The null tests resulted in curves that approximate primary creep. A logarithmic equation was fit to the data to allow the dimensional change due to temperature to be evaluated in the context of the total creep strain. The dimensional change is substantially less for Alloy 5 (Fig. 1b), yet the total strain at a given time, both with and without the contribution of the dimensional change due to aging, is less for Alloy 2 (Fig. 1a).

It can also be seen that the most of the contribution to the total strain due to aging occurs during the primary creep stage.

The average rate of strain in the linear secondary creep portion of the creep curve was measured for each test. These results are typically plotted as $\ln(\text{steady state creep rate})$ versus $\ln(\text{applied stress})$ and are shown in Figure 2a and 2b for the total strain. The slopes for both alloys are linear. The experimentally determined steady state creep rates for both alloys are listed in Table 1.

Times to total creep extension of 0.25, 0.5, and 1% were obtained from the creep data. These values were plotted as a function of $\ln(\text{stress})$ for each temperature. Figure 3 shows the data for time to 1% strain for both alloys.

If equations (1), (2), (3) are applicable to Alloy 2 and 5, a plot of the natural log of time to any fixed creep strain as a function of the natural log of stress should be linear with a slope of $-n$. It can be seen in Figure 3 that this does, indeed hold. The best fit for the slope of the curves for Alloy 2 is 3.5, in agreement with the results of $n = 3.5$ obtained by Murphy, et al⁴. The best fit for the slope of the curves for Alloy 5 is 3.9. In addition, a plot of the natural log of time to a fixed creep strain versus the reciprocal of the T at constant stress should be linear with a slope of Q/R . The time to 1% creep strain at 40 MPa as a function of the reciprocal of test temperature is shown in Figure 4. For both alloys and over the range of stresses used, the activation energy for creep, Q , is in agreement with the value of 106 kJ/mol obtained by Murphy, et al⁴. The values of the constant C' have been calculated for the two alloys at the three strain values using the value of $n = 3.5$ and $Q = 106$ kJ/mol. The results are shown in Table 2. The relationship of C' with the creep strain is non-linear, as shown in Figure 5, where the previously determined C' values for Alloys 3, ZA-8 and ZA-27 have been included.

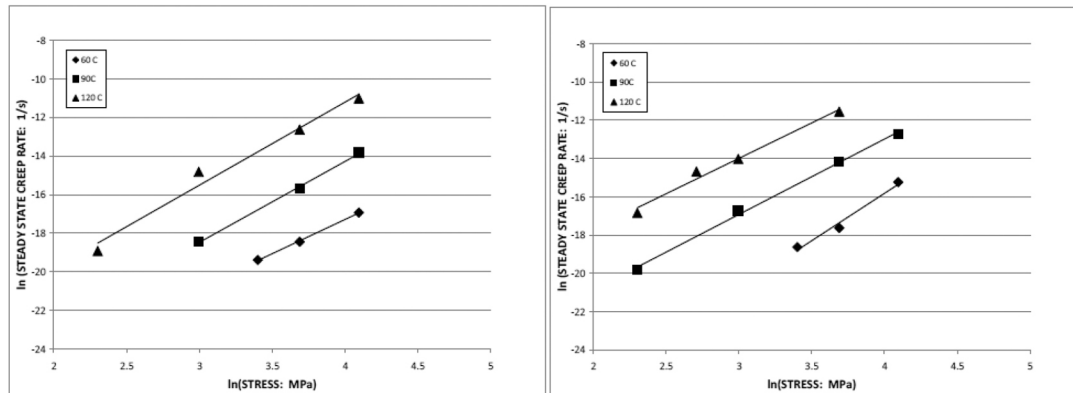


Figure 2. Steady state creep rate. 2a: Alloy 2. 2b: Alloy 5.

Table 1. Steady state creep rates (s^{-1}) for Alloy 2 and 5, total creep strain and creep strain adjusted for dimensional change due to aging.

Alloy	Temp. (°C)	Stress (MPa)	steady state creep rate (true creep strain) s-1	steady state creep rate (true strain w/o aging) s-1	alloy	Temp. (°C)	Stress (MPa)	steady state creep rate (true creep strain) s-1	steady state creep rate (true strain w/o aging) s-1
2	60	30	3.8E-09	3.5E-09	5	60	30	8.1E-09	8.1E-09
		40	9.7E-09	9.1E-09			40	2.2E-08	2.2E-08
		60	4.4E-08	4.3E-08			60	2.4E-07	2.4E-07
2	90	10			5	90	10	2.5E-09	2.5E-09
		20	9.6E-09	8.3E-09			20	5.4E-08	5.3E-08
		40	1.6E-07	1.3E-07			40	7.0E-07	6.9E-07
		60	9.9E-07	9.5E-07			60	3.0E-06	3.0E-06
2	120	10	6.0E-09	5.2E-09	5	120	10	4.9E-08	4.9E-08
		15					15	4.2E-07	4.1E-07
		20	3.7E-07	3.6E-07			20	8.2E-07	8.1E-07
		40	3.3E-06	3.1E-06			40	9.7E-06	9.6E-06
		60	1.6E-05	1.5E-05			60		

The values from Figure 5 can be used with Equation 3 and the values of n and Q given in this paper to determine the combinations of stress, temperature and time that give values of total strain in the range 0.2-1% for these 5 alloys.

Table 2. Values of the creep constant C' for Alloy 2 and Alloy 5

strain	0.25%	0.50%	1.00%
Alloy 2	-13.75	-12.65	-11.61
Alloy 5	-14.61	-13.56	-12.69

Ageing of Zinc Casting Alloys

The mechanical properties of zinc alloys can change over time because of ageing effects. Zinc alloys age at room temperature because of their low melting point that permits a relatively high amount of diffusion at room temperature. The creep results reported above show the important effect of ageing on the dimension changes of Alloy 2 and its influence on creep behavior. Natural ageing is typically managed by using a relatively short artificial ageing heat treatment.

To investigate ageing effects, 50 × 150 mm die cast coupons of zinc alloys 2,3 and 5 with compositions confirming to EN12844 were cast with thicknesses of 0.8, 1.5 and 3 mm using a Frech Type DAW 80 hot chamber die casting