T H E   A R C H I V E   O F   M E C H A N I C A L   E N G I N E E R I N G

VOL. LVI   2009   Number 4

Key words: creep, low cycle fatigue, aluminium alloys

LECH DIETRICH *, *AGNIESZKA RUTECKA* *, *ZBIGNIEW L. KOWALEWSKI* *

ASSESSMENT OF EXPLOITATION PROPERTIES OF CAST ALUMINIUM ALLOYS ON THE BASIS OF CREEP AND LCF INVESTIGATIONS

The paper presents experimental results of creep and low cycle fatigue (LCF) tests carried out on the as-received cast aluminium alloys with different chemical composition and porosity. The test programmes contain creep investigations under step-increased stresses at different temperatures, and cyclic plasticity under different strain amplitudes and temperatures.

1. Introduction

In spite of the great progress in modelling of material behaviour achieved during last decade, there is still a necessity to determine a model which would describe complex material processes more accurately. Among many problems to be solved, a proper model selection and its verification on the basis of experimental data seems to be the most important nowadays. Since the creep and fatigue mechanisms differ from each other, it is important to perform experiment on both kinds of mechanisms to be able to verify models.

The paper presents the creep and LCF results of the AlSi8Cu3 and AlSi7MgCu0.5 cast aluminium alloys. For both materials, two levels of porosity were considered. Low porosity material (melt) was degassed during production to achieve the density index less than 3%. The high porosity material was not degassed in order to enlarge the density index up to a value higher than 6%.

Up to now, many efforts are made to carry out investigations whose main objective is to find such a parameter, which would allow for describing a dam-

* *Institute of Fundamental Technological Research P.A.S., ul. Pawińskiego 5b, 02-106 Warsaw, tel.+48 22 8261281 ext. 262, e-mail: ldietr@ippt.gov.pl, agnieszka.rutecka@ippt.gov.pl, zkowalew@ippt.gov.pl*

age of the material as accurately as possible [1]. Among many possibilities, there is one which, in opinion of many researchers, is a promising tool in effective identification of damage development. This is a damage parameter related to the slope variation of the tangential, being a graphical representation of the elastic modulus at zero stress level. However, applicability of the elastic modulus as a damage parameter, in the case of the considered aluminium alloys, cannot be confirmed by the results presented in this paper. The paper provides experimental data which are useful for verifying new and existing numerical models [2-10].

2. Creep tests for the cast aluminium alloys with different chemical composition and porosity

2.1. Details of creep tests

Creep investigations were carried out on plane specimens with dimensions shown in Fig. 1. The tests were performed at different temperatures, 180°C, 200°C, 220°C and 240°C. The specimen was installed in the creep testing machine, and then heated up to the selected temperature, kept in this temperature for 20 hours, and then it was step-loaded every 5 or 10 hours to obtain a tensile stress equal to 25 MPa, 50 MPa, 75 MPa, 100 MPa and 125 MPa. The programme of creep tests is presented in Fig. 2.

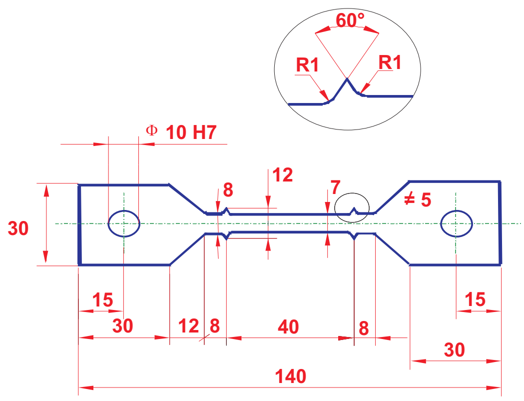

Fig. 1. Specimen used for creep tests

2.2. The creep results

Looking at the creep curves obtained at 220°C we can observe an interesting effect in the period of the first 15 hours (Fig. 3b). The creep curve for the low porosity AlSi8Cu3 is located under the creep curve obtained for the

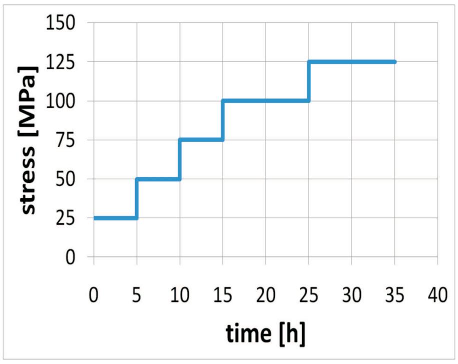

Fig. 2. Programme of creep tests

material of the same composition but of high porosity. Thus, it indicates a higher strain response of the high-porosity material. Contrary to this fact, the creep curves obtained after 15 hours of tests exhibit higher strain response and strain rates of the low porosity material in comparison to the same material of high porosity. Moreover, a tertiary creep of the low porosity AlSi8Cu3 appeared after 21 hours (Fig. 3a). The results of creep tests carried out at elevated temperature (240°C) showed similar strain rates (creep resistance) and lifetime (creep durability) for the material of low and high porosity.

(a) (b)

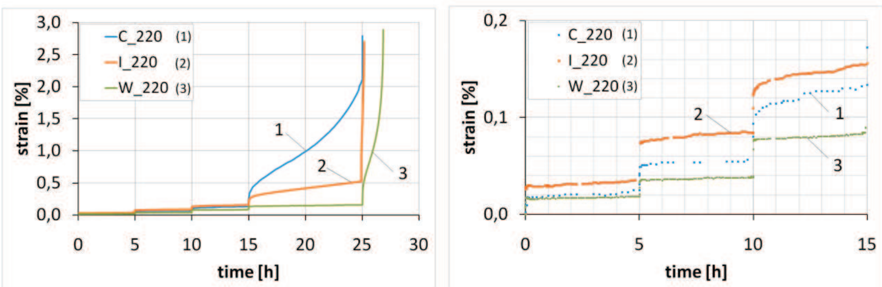

Fig. 3. Comparison of the creep curves for: low porosity AlSi8Cu3 (C_220), high porosity AlSi8Cu3 (I_220) and low porosity AlSi7MgCu0.5 (W_220) tested at 220°C; (a) – full creep curves; (b) – magnified view of curves at period from 0 to 15 [h]

Creep curves in Figs. 3a and 3b indicate also the strongest creep resistance and the longest lifetime of the low porosity AlSi7MgCu0.5. As it is clearly seen, the creep deformation is significantly smaller in the period of the first 25 hours of the test. However, after next step loading up to 125 MPa, all three creep stages appeared and the specimen failed after 27 hours.

A comparison of the creep curves for the materials investigated at all applied temperatures indicates a decrease of creep resistance and durability with the increase of test temperature. It is expressed by higher strain rates and shorter lifetimes at elevated temperatures. The representative creep curves for the low porosity AlSi8Cu3 tested at different temperatures are presented in Fig. 4.

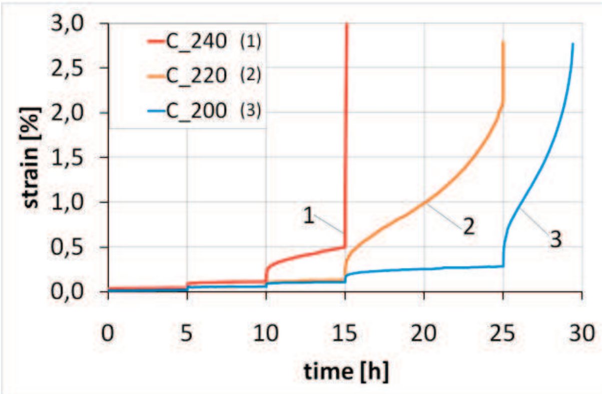

Fig. 4. Comparison of the creep curves for the low porosity AlSi8Cu3 tested at three selected temperatures: 200°C (C_200), 220°C (C_220), 240°C (C_240)

3. The low cycle fatigue tests (LCF) for the cast aluminium alloys with regard to their chemical composition and porosity

3.1. Details of LCF tests

The LCF tests were carried out on the cylindrical specimens with dimensions showed in Fig. 5. Two aluminium alloys were examined: AlSi8Cu3 and AlSi7MgCu0.5. First of them was tested for two levels of porosity (low and high), whereas the second one for low porosity only. The programme consisted of three blocks of 100 tension-compression cycles each, as it is schematically presented in Fig. 6. The strain-controlled experiments were carried out for the following amplitudes: block 1 ±0,002 (1), block 2 ±0,0035 (2), block 3 ±0,005 (3), in sequences: 123, 312, 231.

3.2. The LCF results

A comparison of the hysteresis loops for the first two cycles of block 3 with the highest value of strain amplitude (±0,005 (3)) is presented in Figs. 7, 8. Three different loading histories (sequences of strain amplitudes) were considered: 123 (Fig. 7a), 231 (Fig. 7b) and 312 (Fig. 8). The tests were carried out at room temperature, and at elevated temperatures of 150°C and 250°C.

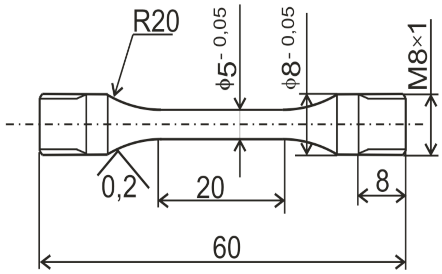

Fig. 5. Specimen used for LCF tests

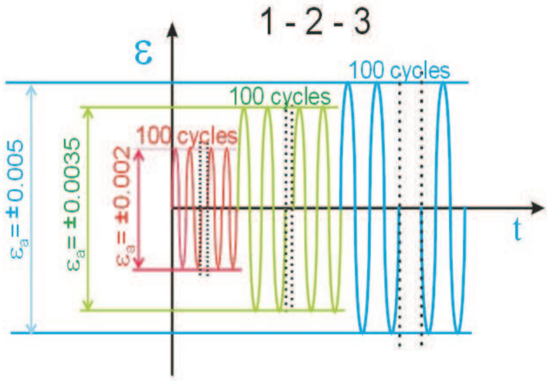

Fig. 6. Programme of LCF tests

As it is clearly seen, the best strength (expressed by the narrowest hysteresis loops), the highest yield points and hardening moduli were observed for the alloy AlSi7MgCu0.5. The last two parameters were lower for the high porosity AlSi8Cu3, and the smallest for the same material tested in the case of low porosity (Figs. 7, 8). Moreover, the stress response decreased with temperature growth.

The cyclic hardening for the block 3 of 231 and 123 sequences of strain amplitudes is insignificant (Fig. 7), which can be related to the prior loading history. Contrary to this fact, the cyclic hardening can be observed for the block 3 of 312 sequence (Fig. 8) for the materials tested at 150°C. However, in the case of temperature equal to 250°C, the effect can be neglected again.

A comparison of the hysteresis loops allows us to identify the anisotropy expressed by significant differences between absolute values of stress under tension and compression obtained for the same magnitude of strain, Figs. 7, 8. The effect was observed for the majority of tested specimens manufactured for the AlSi7MgCu0.5. Only a few of them exhibited the same effect in the case of AlSi8Cu3. It can be explained by the fact that during compression some of voids tend to close themselves, and hence the forces are carried by a larger part of the specimen's cross-section. As a consequence, the nominal stress under compression becomes greater than that under tension. This effect was not observed at the highest temperatures.

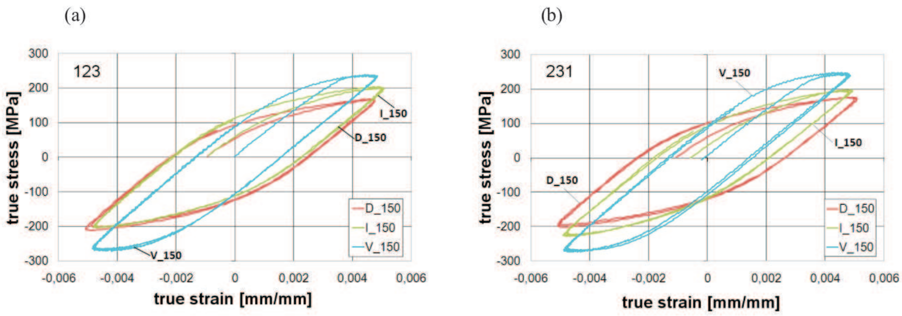

Fig. 7. Hysteresis loops for first two cycles of the block with amplitude ±0,005 (3) for: low porosity AlSi7MgCu0.5 (V_150), low porosity AlSi8Cu3 (D_150) and high porosity AlSi8Cu3 (I_150), tested at 150°C with the following sequences of blocks: (a) 123 and (b) 231

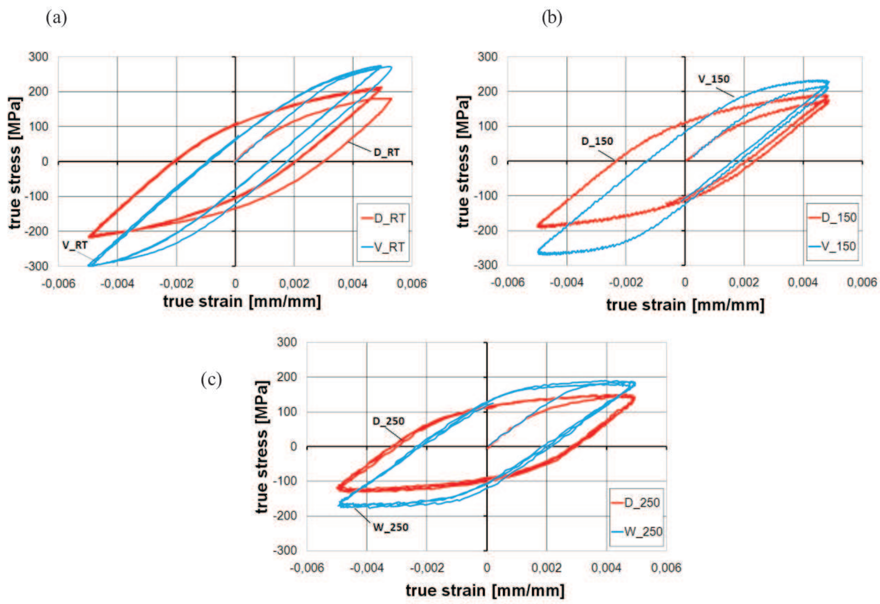

Fig. 8. Hysteresis loops for first two cycles of the block with amplitude ±0,005 (3) for: AlSi7MgCu0.5 (V, W) and AlSi8Cu3 (D) with low porosity, tested with the 312 sequence. Tests were carried out at (a) room temperature; (b) 150°C; (c) 250°C

It is easy to notice that the tangential, being a graphical representation of the elastic modulus at zero stress level, keeps almost constant angle during tests irrespective of the test temperature, porosity and loading history. It is visible especially during unloading for which the rectilinear segments of unloading characteristic are parallel to the loading curve in its elastic part. In contrast to the tangential elastic module, the secant one varies depending on the parameters mentioned above.

4. Conclusions

The low-porosity AlSi7MgCu0.5 exhibits better strength parameters under fatigue and creep conditions than the AlSi8Cu3.

The LCF and creep test results of low porosity AlSi8Cu3 show weaker resistance under fatigue and creep conditions in comparison to those for the high porosity material. It was noticed that a greater size voids can be treated as initiators of cracks during high cycle fatigue. At low cycle fatigue, they are the main reason of failure and lifetime reduction. On the other hand, the lower porosity, i.e. smaller size voids, stimulates diminution of creep resistance and decrease of stress response during the LCF tests. It must be emphasised that the level of porosity was only determined in selected samples prepared for microstructural observations before mechanical investigations. In order to explain the complex phenomena related to creep and fatigue of the materials tested, the porosity level should be determined in the region of the fracture cross-section.

Similar values of the tangential elastic modulus were obtained during the first and last cycle of the LCF tests. Therefore, it cannot be taken as the measure of damage development. This fact contradicts previous concepts concerning this matter, put forward by researchers who investigated some other materials.

Steady-state creep rate, lifetime and hardening moduli determined during experiments, create the data base which can be used for identification and verification of new, as well as currently applied numerical models.

The investigations carried out in this research were done within the framework of the NADIA Project, Sixth Framework Programme, New Automotive Components Designed for and Manufactured by Intelligent Processing of Light Alloys, 2006-2010.

Manuscript received by Editorial Board, June 10, 2009;
final version, August 03, 2009.

REFERENCES

[1] Lemaitre J.: A course on damage mechanics, Springer-Verlag, 1992.
[2] Hecker S. S.: Experimental studies of yield phenomena in biaxially loaded metals, in: Constitutive Equations in Viscoplasticity: Computational and Engineering Aspects, The Winter Annual Meeting of The American Society of Mechanical Engineers, New York City, NY, Ed. Stricklin and Saczalski, ASME, AMD, 20, 1-33, 1976.
[3] Chaboche J.: Viscoplastic constitutive equations for the description of cyclic and anisotropic behaviour of metals, Bull. Acad. Pol. Sci. Ser. Techn., 25, 33-39, 1977.
[4] Chaboche J. L.: Constitutive equations in creep-fracture damage, in: Engineering Approaches to High Temperature Design, Eds. B. Wilshire, D.R.J. Owen Pineridge Press, Swansea, 177-235, 1983.
[5] Hayhurst D.R.: On the role of creep continuum damage in structural mechanics, in: Engineering Approaches to High Temperature Design, Eds. Wilshire B., Owen D.R.J., Pineridge Press, Swansea, 85-176, 1983.
[6] Dyson B.F., Gibbons T.G.: Tertiary creep in nickel-base superalloys: analysis of experimental data and theoretical synthesis, Acta Metall., 35, 2355-2369, 1987.
[7] Dunne F.P.E., Hayhurst D.R.: An expert system for the determination of creep constitutive equations based on continuum damage mechanics, J. Str. Anal., 26, 185-191, 1991.
[8] Dunne F.P.E., Makin J., Hayhurst D.R.: Automated procedures for the determination of high temperature viscoplastic damage constitutive equations, Proc. R. Soc. Lond. A, 437, 527-544, 1992.
[9] Chaboche, J.L.: "Unified Cyclic Viscoplastic Constitutive Equations: Development, Capabilities and Thermodynamic Framework", Unified Constitutive Laws of Plastic Deformation, Ed. A.S. Krausz and K. Krausz, Academic Press, pp. 1-68, 1996.
[10] Yoshida, F., Uemori T.: "A model of large-strain cyclic plasticity describing the Bauschinger effect and workhardening stagnation", International Journal of Plasticity Vol. 18, pp. 661-686, 2002.

Ocena właściwości eksploatacyjnych stopów aluminium na podstawie badań pełzania i niskocyklowego zmęczenia

Streszczenie

Praca przedstawia wyniki badań eksperymentalnych zjawiska pełzania i niskocyklowego zmęczenia (LCF) dla odlewniczych stopów aluminium w stanie dostawy, o różnym składzie chemicznym oraz porowatości. Przeprowadzony program badań obejmował pełzanie przy skokowo narastających obciążeniach w różnych temperaturach oraz cykliczną plastyczność dla różnych amplitud obciążenia i temperatur.