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Modifying a Coffin-Manson curve of an aluminium alloy AlSi9Cu3 by considering an effect of macro porosity

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Introduction

Light-weight design represents one of the possibilities for minimizing the carbon footprint in the automotive industry. The most complicated light-weight components for large-series production are often manufactured with a pressure die-casting process. To improve the economies of scale multi-cavity tools are often applied in practice. However, with such an approach it is often difficult to economically manufacture parts without any macro porosity. Porosity is a defect in the product, but if it is possible to properly evaluate its influence to the structural durability, such porous parts need not to be scrapped. One of the widely used aluminum alloy in the automotive industry is AlSi9Cu3. In the past a thorough research was already done to predict the fatigue life of porous specimens from the AlSi9Cu3 alloy with finite element simulations by considering the actual distribution of macro pores in the tested specimens. In this paper a novel approach is presented, which enables finite-element simulations of porous parts with a homogenous solid model. The key enabling technique is to modify the material's Coffin-Manson curve to account for the effects of typical porosity, which is found in the product. The modification rules are derived from a series of finite-element simulations that were carried out for typical geometrical aspects of the macroscopic porosity. The combinations of geometric parameters of porosity were set-up using the Taguchi array. The simulation results were compared to the experimentally determined fatigue lives for specimens with different grades of well-developed macroscopic porosity.

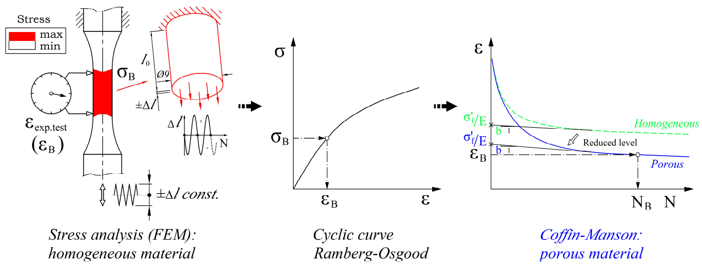

Figure 1. A sequence of steps to estimate the fatigue life of a porous structure.

Results

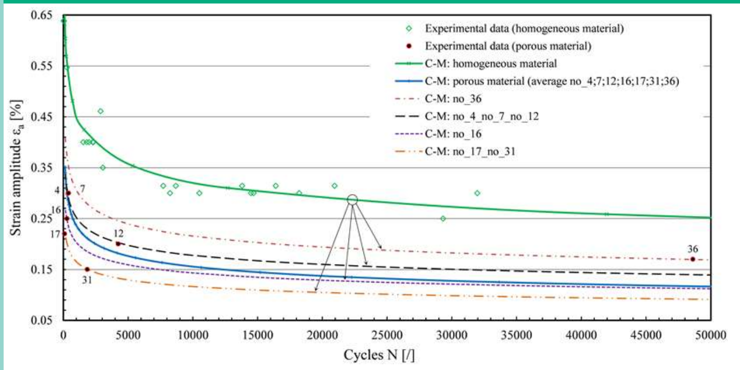

Figure 2. How to shift a C-M curve for homogeneous material to account for the porosity?

- The tested sample of no. 12 withstood N = 4243 cycles at a load of ε_a = 0.2%.
- Based on µ-CT examinations of the samples, the following parameters were determined: the size, position, and orientation of all pores.

Figure 3. After LCF procedure tested and the µ-CT scanned specimens.

Methodology – shifting the elastic part of the C-M curve

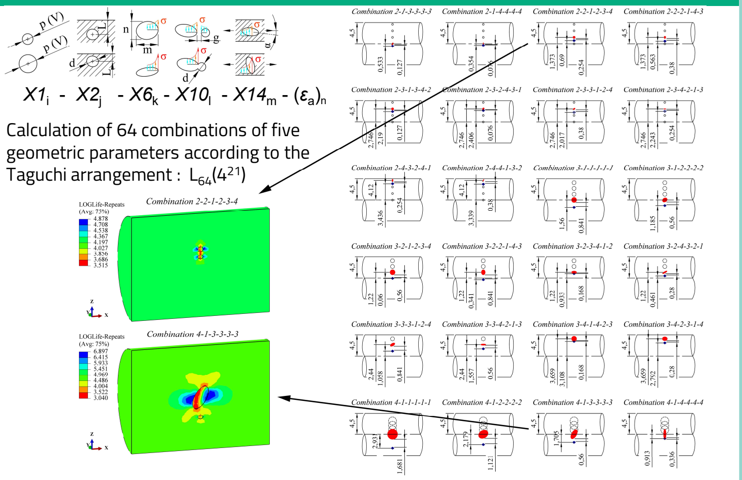

Figure 4. Calculating the fatigue life for different combinations to determine the parameters σ'_f and b.

$$\underbrace{\left[\varepsilon_a - \varepsilon'_f\left(2\cdot N_f\right)^c\right]}_{K(N_f)}\cdot E = \sigma'_f\left(2\cdot N_f\right)^b$$

$$Y = \log_{10}\left[K\left(N_f\right)\cdot E\right] = \log_{10}\sigma'_f + b\cdot\log_{10}\left(2\cdot N_f\right) \quad \text{(eq. 1)}$$

Coffin-Manson (C-M) equation

$$\log_{10}\sigma'_f = s_0 + s_1\cdot x1 + s_2\cdot\left(\frac{1}{x2}\right) + s_3\cdot x6 + s_4\cdot\left(\frac{1}{x10}\right) + s_5\cdot x14$$

$$b = b_0 + b_1\cdot x1 + b_2\cdot\left(\frac{1}{x2}\right) + b_3\cdot x6 + b_4\cdot\left(\frac{1}{x10}\right) + b_5\cdot x14 \quad \text{(eq. 2)}$$

Solving for the coeff. of the C-M eq. with regression

Table 1. Calculation of regression coefficients to determine parameters $\log_{10}\sigma'_f$ and b.

$\log_{10}\sigma'_f$	s_0	s_1	s_2	s_3	s_4	s_5
IBM SPSS	2.743	0.029	0.011	0.209	0.006	0.015
b	b_0	b_1	b_2	b_3	b_4	b_5
IBM SPSS	−0.138	−0.015	−0.003	−0.027	0.003	−0.002

Conclusion

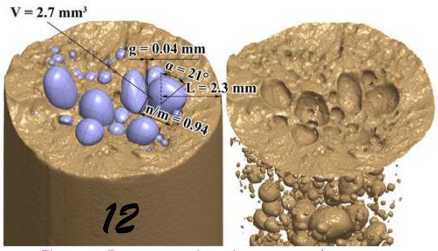

Figure 5. Reverse engineering on sample no. 12.

Table 2. C-M homogeneous material AlSi9Cu3.

σ'_f	1087
b	− 0.152
ε'_f	0.0001
c	− 1.605

Shifted C-M curve for sample no. 12 is obtained by calculating the coeff. according to eq. 2 on the basis of the data from Table 1 and Fig 5. The new data was put into eq. 1 to get the results in Table 3 and Fig. 6.

Table 3. C-M porous material AlSi9Cu3 no. 12

σ'_f	705
b	− 0.172
ε'_f	0.0001
c	− 1.605

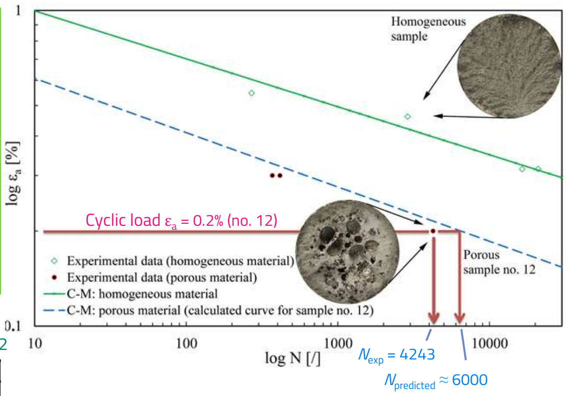

Figure 6. Display of the calculated level of the C-M curve for the sample no. 12.

Acknowledgements

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