

EXPERIMENTAL-NUMERICAL ANALYSIS OF FRACTURE MECHANICAL PROPERTIES OF AL/MG COMPOUNDS

Thomas Lehmann, Martin Stockmann

Chemnitz University of Technology, Faculty of Mechanical Engineering, Department of Solid Mechanics, Division Experimental Mechanics, 09107 Chemnitz, Germany

Corresponding author: thomas.lehmann@mb.tu-chemnitz.de

1. Introduction

Because of the need to save energy and resources, light weight materials are becoming more and more important. In this work, rotationally symmetric, aluminum-sheathed magnesium rods [1], produced by hydrostatic coextrusion, are investigated. The focus in this paper is on the determination of fracture mechanical properties of the newly developed AlMgSi1/AZ31 compounds (outer diameter 20 mm, core diameter 15 mm).

2. Linear elastic fracture mechanics of interface cracks

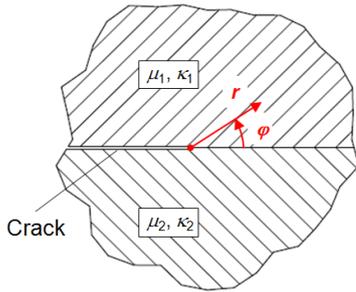


Fig. 1: Plane interface crack model

For the displacement discontinuities in r and φ direction at the near field of interface crack tips (Fig. 1), the following equation can be written in complex notation [2]

$$\Delta u_\varphi(r) + i\Delta u_r(r) = \frac{8K}{E^*(1+2i\eta)\cosh(\pi\eta)} \sqrt{\frac{r}{l_R}} \left(\frac{r}{l_R}\right)^{i\eta} \quad (1)$$

The reference length l_R in Eq. (1) is arbitrary. The components of the displacement discontinuities $\Delta u_j(r)$ at the crack flanks are given by

$$\Delta u_j(r) = u_j(r, \varphi = -\pi) - u_j(r, \varphi = \pi) \quad j = r, \varphi. \quad (2)$$

Furthermore, the complex stress intensity factor K is defined by

$$K = K_1 + iK_2 \quad |K| = \sqrt{K_1^2 + K_2^2} \quad (3)$$

At interface cracks, mode I and mode II conditions always occur together and the indices

are changed from I to 1 and from II to 2. Another input value of Eq. (1) is the mixed Young's modulus E^* in the plain strain state ($E_{1/2}$ - Young's moduli, $\nu_{1/2}$ - Poisson's ratios)

$$E^* = \frac{2E'_1 E'_2}{E'_1 + E'_2} \quad E'_{1/2} = \frac{E_{1/2}}{1 - \nu_{1/2}^2} \quad (4)$$

The bimaterial constant η is determined by

$$\eta = \frac{1}{2\pi} \ln \frac{\mu_2 \kappa_1 + \mu_1}{\mu_1 \kappa_2 + \mu_2} \quad (5)$$

with the elastic constants $\kappa_{1/2}$ and $\mu_{1/2}$ (in the plain strain state)

$$\kappa_{1/2} = 3 - 4\nu_{1/2} \quad \mu_{1/2} = E_{1/2} / 2(1 + \nu_{1/2}) \quad (6)$$

Finally, for fracture mechanical analysis, the absolute value of the stress intensity factor $|K|$ can be calculated by using Eq.'s (1) to (6)

$$|K| = \frac{\sqrt{2\pi E^*} \cosh(\pi\eta)}{8\sqrt{r}} \sqrt{(\Delta u_r^2(r) + \Delta u_\varphi^2(r))(1 + 4\eta^2)} \quad (7)$$

and the energy release rate G (following [2]) is

$$G = \frac{\pi E^*}{32r} (\Delta u_r^2(r) + \Delta u_\varphi^2(r))(1 + 4\eta^2) \quad (8)$$

$|K|$ and G are independent of the reference length l_R . If there are no differences between the elastic properties of the single materials, then $\eta = 0$ and the equations result in those, which are valid for the homogeneous case [3].

3. Experimental-numerical method

3.1 Procedure

The procedure for the determination of fracture mechanical values is presented in Fig. 2. The respective output values of the experiments and numerical simulations are written in the elliptic fields.

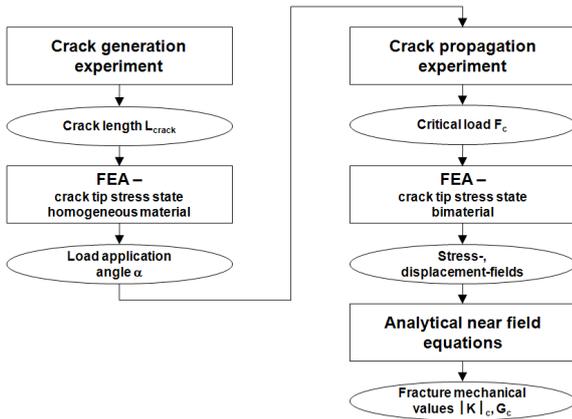


Fig. 2: Procedure for fracture mechanical analyses

3.2 Experiments

For crack generation, notched specimens were clamped on the one side and loaded quasistatically by a punch on the other side. The results are crack lengths L_{crack} between 3.5 and 5 mm. The special specimen geometry is given in Fig. (3) (thickness $t = 7$ and 5 mm).

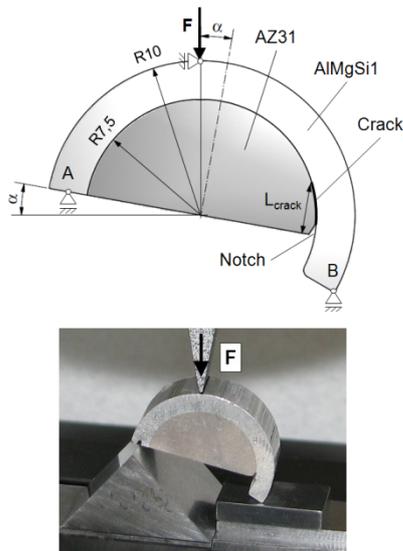


Fig. 3: Load case (upper) / part of the experimental setup of the crack propagation tests (lower)

Furthermore, the load case and the experimental realization of the crack propagation tests are demonstrated in Fig. (3). The load application angle α depends on the specimen crack length L_{crack} . This angle is determined by a FE analysis (paragraph 3.3) using the criterion of a mode I stress state in the homogeneous case. The specimens are loaded (quasistatically) by a punch and supported by two movable bearings at the Points A and B. After reaching the critical (maximum) force F_c , brittle crack propagation occurs, which is associated with an abrupt force decrease.

3.3 Numerical simulations

The numerical simulations were done with ANSYS 12.1, using a fine 2d mesh (plain strain state) and quarter-point elements at the area around crack tip [3]. The input values for the simulations of the crack propagation experiments are the critical forces F_c . In Fig. (4), an example of the σ_ϕ -field is given. The output values for the fracture mechanical calculations are $\Delta u_r(r)$ and $\Delta u_\phi(r)$ at the crack flanks.

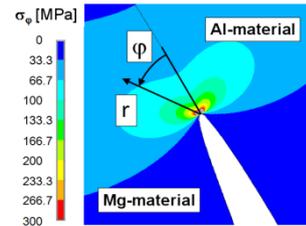


Fig. 4: Stress field σ_ϕ at the crack tip region

4. Fracture mechanical results

Critical fracture mechanical values are finally calculated by means of the FEA results, Eq.'s (7) and (8) as well as the limiting values

$$|K|_c = \lim_{r \rightarrow 0} |K|_{FEA}(r) \quad G_c = \lim_{r \rightarrow 0} G_{FEA}(r). \quad (9)$$

Tab. 1: Fracture mechanical results of the test series

$ K _c$ [MPa m ^{1/2}]	G_c [N/m]
2.3..3.3	88..178

In case of the used materials ($E_{Mg} = 45$ GPa, $E_{Al} = 70$ GPa, $\nu_{Mg} = 0.35$, $\nu_{Al} = 0.33$), the influence of the bimaterial constant $\eta = 0.013$ is low, so that it can be reasoned that $|K|_c \approx K_{Ic}$. The fracture mechanical behaviour of the interface is independent of the crack length and can be classified as brittle (Tab. 1).

Acknowledgements: The authors thank the German Research Foundation for financial support of this work, which is a part of SFB 692, subproject B3.

References

- [1] Lehmann, T., Stockmann, M., Naumann, J., Experimental and Numerical Investigations of Al/Mg Compound Specimens under Load in an Extended Temperature Range, FME Transactions, 37-1 (2009), 1-8.
- [2] Molter, J., Untersuchung mechanischer Eigenschaften von Schichtsystemen, PhD Thesis (2001).
- [3] Kuna, M., Numerische Beanspruchungsanalyse von Rissen, Vieweg+Teubner Verlag, (2010).