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FATIGUE TESTING OF SANDWICH STRUCTURES USING THE SINGLE CANTILEVER BEAM TEST AT CONSTANT ENERGY RELEASE RATES

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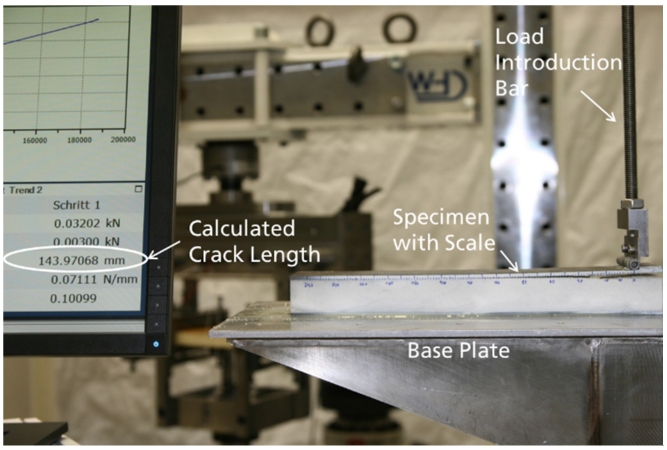
1. INTRODUCTION

Cyclic Single Cantilever Beam (SCB) tests were used to characterize the fatigue behavior of interface fracture toughness of a foam core sandwich structure. First foam core sandwich structures were tested in SCB, where alternating loads were carried out. The cyclic alternating load tests were performed force-controlled with peak value control, resulting in a sinusoidal force curve and a nearly sinusoidal course of the path. Also classical fatigue tests are performed either under a constant force or constant displacement amplitude. Using this method of crack progress testing in the SCB test, the energy release rate (ERR) G increases significantly with increasing crack length until it exceeds the critical static value of the ERR and leads to unstable crack growth. In this way, only a few values within the area of stable crack growth can be determined. A better way to determine the crack growth under cyclic loads represents the Constant-G method. In this method, the crack tip is kept under almost constant stress. The necessary algorithms for this method were therefore developed. Afterwards it was implemented in the test control. Additional test specimens were tested and the method was validated on various sandwich specimens.

2. SINGLE CANTILEVER BEAM TEST

The concept of the Constant-G method is based on the experimental determination of the relationship between the compliance of the loaded sample and the crack length. The method allows calculating the ERR already during the current test from the force and displacement signals of the testing machine for each load cycle. By controlling the test force over the entire test duration, the ERR is kept constant during the crack growth (Fig. 1, left). Consequently, it is achieved that more values can be determined in the area of stable crack growth, so that a reliable determination of the fatigue crack growth by means of Paris [4] law is possible. In order to check the method, the actual crack length is recorded simultaneously on the basis of photographic documentation and then evaluated in a comparative manner .

Before the starting the test, a desired level of ERR can be set in the test software. For this, the critical ERR of the material must be known. If it is not known, preliminary tests must be carried out to determine critical ERR (G_{IC}). After each load cycle, the compliance is determined from the force and traverse path values of the testing machine. From the known relationship between compliance and crack length (see Fig.1 right), the present crack length in the sample can be calculated. Thus, it is again possible to calculate the ERR acting on the crack tip in this load cycle. In a further step, the test computer compares the calculated ERR with the default value. If both values match, a new load cycle is carried out with the same traverse path. If not, the minimum and maximum of the applied displacement must be adjusted. The basic procedure for the control is shown in Fig. 2. For two different sandwich materials (foam core and honeycomb core) the fitted equations of ERR depending on are shown.



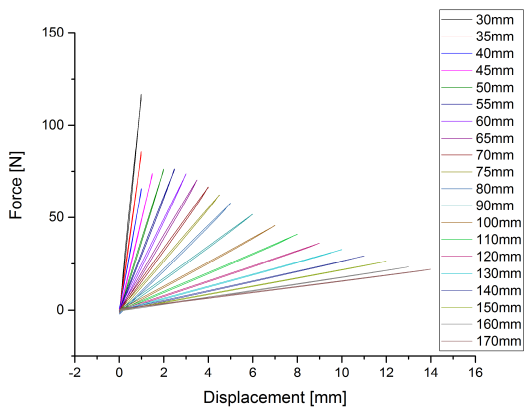


Fig. 1: Compliance of Foam Core (a) and Honeycomb Core Sandwich (b).

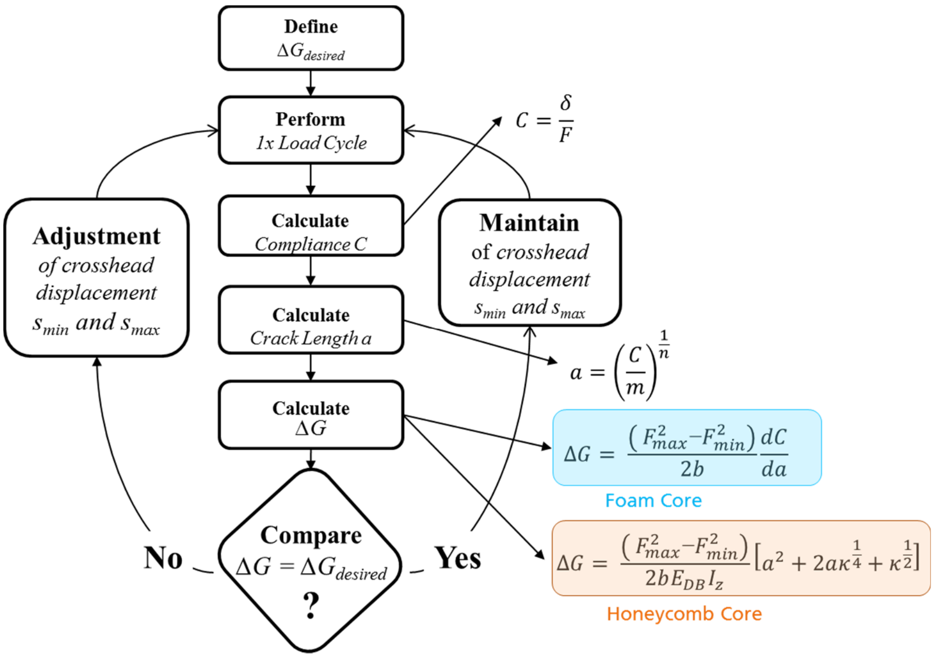


Fig. 2: Workflow of SCB-Test at constant Energy Release Rate.

In this study, all experiments were carried out path-controlled. A force-controlled procedure is also possible. In Fig.3, the control loop is illustrated by a block diagram. A setpoint of the ERR is given to the control software, which passes control signals to the test cylinder. The test cylinder extends and adjusts a traverse path, which sets a specific stress field at the crack tip. The random nature of the crack progression disturbs this stress field. This leads to a change in the actual ERR. The true ERR at the crack tip is determined indirectly via the measured force and displacement values of the testing machine. The calculated ERR is given back to the control software and compared with the setpoint to calculate the error. This closes the control loop and the control software calculates new control values for the test cylinder based on the deviation from the setpoint to actual value. The control software regulates the upper and lower limits of the traverse path _min and _max. For the upper limit, the control tries to reach _$G_{desired}$ and to select the lower limit at the same time, so that the desired force ratio R prevails. For the calculation of the ERR, three values are averaged to reduce measurement noise.

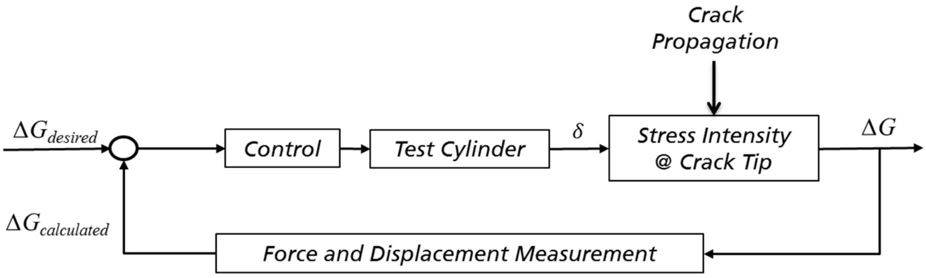


Fig. 3: Block diagram of the Constant-G method.

3. CRACK GROWTH RATE RESULTS

Analytic and experimental relationships between compliance and crack length can be used to determine the crack length. It has been shown that the calculation of the crack lengths, using the compliance of the cover layers, shows good agreement with the measured values. The ERR can be determined from these values. It is recalculated after each oscillation cycle. As a result of the experiment, the crack growth curves and the lifetime of the materials can be determined, see Fig. 4.

Overall, the Constant-G method can be seen as complementary to other fracture mechanics fatigue tests. It is particularly useful when the area of stable crack growth is very small and needs to be characterized with a high accuracy. Only a limited number of sample bodies were available for the experimental investigation. A larger sample size is recommended to optimize the method and to validate future experiments statistically.

For the exact determination of the prevailing ERR, it is important to be able to describe the correlation between compliance and crack length as precisely as possible. It turns out that this correlation differs from the calculated values, especially with large crack lengths. Dynamic measurement of the actual crack length during the SCB test would provide a more realistic view of the stress state of the crack tip. For this purpose, possible measuring methods were presented that allow an automated determination of the crack length in sandwich materials. Time Domain Reflectometry, electrical resistance measurement, and acoustic emission measurement are promising [5,6]. The suitability and quality of these methods in relation to SCB experiments on sandwich samples should be investigated and quantified in further experiments. The range of constant crack growth that occurs for the tested material combinations within very narrow limits of ERR can be described by a higher number of measurements using the developed test method. It enables more reliable statements on crack progress behavior. This has contributed to a better understanding of the fatigue behavior of pre-damaged sandwich materials under global opening mode I loading. The applicability has been demonstrated for sandwich materials with PMI rigid foam.

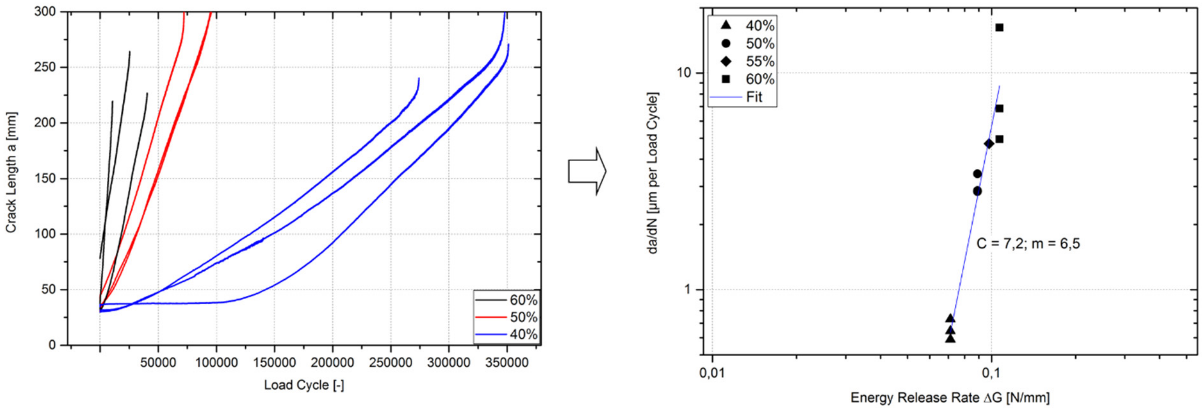


Fig. 4: Crack Length vs. Load Cycles (left), Crack Growth Diagram fitted by PARIS-law (right).

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