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TESTING OF CONTAINERS MADE OF GLASS-FIBER REINFORCED PLASTIC WITH THE AID OF ACOUSTIC EMISSION ANALYSIS

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Testing of containers made of glass-fiber reinforced plastic with the aid of acoustic emission analysis

Pressurizing of GFK containers, fracture of matrix and fibers, acoustic emission analysis, separation of signals from different sources, evaluation of strength

1. Introduction

The use of fiber-reinforced plastics for the fabrication of highly-stressed construction parts depends to a large degree on the availability of nondestructive or quasi-nondestructive free test methods for quality control. To a greater degree than in the case of homogeneous materials the strength of the composite is affected not only by the kind of components used, fibers and resin matrix, but also by the fabrication parameters which cannot always be completely controlled.

Conventional nondestructive test methods, such as ultrasonic techniques or optical testing, allow the detection of only relatively large defects in the fiber make-up. In addition, even with the test results on hand one cannot determine unconditionally to what extent the discovered defect will have a negative effect on the total behavior of the composite. The acoustic emission analysis (SEA), on the other hand, when the fiber-reinforced con-

* Numbers in margins refer to foreign pagination

struction part is used below its rated load or even up to rated load, makes it possible to detect practically all failure modes, such as their appreciable fiber fractures, delamination between matrix resin and fibers, as well as fractures in the resin matrix. However, the sole registration of sound pulses caused by failure processes, e.g., in the form of curves of the sums of sound pulses, is not sufficient, in most cases, for the evaluation of the useability of the construction piece since, with this method it is not possible to differentiate with reasonable assurance between non-critical and critical failure processes (compare also reference 1).

For the tests, tubes with an internal diameter of 45 mm and a wall thickness of about 3 mm were available. The GFK laminate was produced by the firm of Dynamit Nobel AG as a unidirectional fiber composite. All glass fibers are oriented in the load direction. /91/790 Loading (pressurization) produces an approximately uniaxial stress condition. If such a composite system is subjected only to tension stresses, then its strength is a function of only that of the fibers. If one ignores climatic effects, then delamination between matrix resin and fibers has a negative effect on durability which is no greater than the effect of matrix fractures among the fibers. If such a composite is to be tested by acoustic emission analysis to see if it is acceptable for quality control purposes, then the test results must furnish indisputable indications whether, in a unidirectional composite, fiber fractures have occurred in tension loads up to a maximum of rated loads which must solely be considered as critical. Such fiber fractures can occur, even for adequate sizing of the composite, from damage of the glass fibers during lamination, from non-uniform fiber thicknesses in the composite, or finally from subsequently imposed scores or grooves. On the other hand, if the test shows that no fiber fractures have occurred in the composite up to rated loads, then in this special case one can deduce from the test result that the composite exhibits the durability that was calculated.

2. Experimental technique of the SEA method

As pickups for the acoustic emission narrow -- and broadband piezoelectric converters were used which were attached to the test body with suitable saddle pieces to balance out the curvature of the construction pieces. The reciprocity method [2] was used to calibrate the receivers. The evaluation of the acoustic emission was made from a determination of the amplitude distribution and from a broad-band representation of the signals in the time and frequency frame, figure 1. To conduct the amplitude analysis the narrow-band acoustic emission was passed to seven impulse counters with varying discriminator thresholds. In addition the frequency of the acoustic signals was plotted over the discriminator threshold used such that the dynamics of this plot extended to values above 70 dB.

- For the determination of the amplitude distribution direct physical parameters are measured.
- Through the use of several discriminator thresholds differing from each other SE-events of varying intensity can be recognized.
- The measurement of the amplitude distribution is particularly sensitive because of the narrow-band character of the receivers.
- The height of the amplitude is proportional to the intensity of the sound.
- In comparison the frequency analysis produces information as to the characteristics of the individual signals.

To determine the shape of the signal in the time and frequency frame broad-band sound pulses were stored in a transient recorder (Biomation 8100) and periodically passed to a frequency analyzer with a frequency range between 30 kHz and 1 MHz.

3. Test results

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For a continuously increasing internal pressurization of the test body a hydraulic oil was used whereby it was possible to keep the noises generated by the pressure pump away from the test body by means of pressure hoses located between the pump and the test installation. At a rate of pressurization of about 1 bar/sec the test pieces failed at pressures above 1200 bar which corresponds to a radical tensile stress of 900 N/mm^2; the failure occurred abruptly as shown in figure 2. Parallel to the cylinder axis the radially oriented fibers in the composite tore over a length of 2 to 3 cm. Before the failure occurred, i.e., at lower pressure loads, no external damages could be detected on the construction part. To what extent fiber fractures had occurred before the rupture cannot be determined by optical means although one can surely assume that an appreciable part of the elastic energy in pre-damages of the fibers was stored in the test piece before the rupture occurred.

If we now turn to the results of the acoustic emission analysis, figure 3, we can see that the first signals, i.e., the first damaging events already occur at very low pressures, below 50 bar. The amplitude distribution of these signals is characterized by an exponential function, $J = C \cdot D^{-n}$ whose exponent was found to be $n = 1.1$ to 1.8. In this equation we denote: J = sum of the acoustic impulses; C = constant; D = discriminator threshold; n = slope of the straight lines in the amplitude distribution. The only possible causes for these acoustic signals can be found in matrix fractures or in delamination processes in the axial and the radial layers since fiber fractures cannot be expected at such low pressures.

The number of sound impulses of the characteristic described here increased with increasing pressure; however, a change in the amplitude distribution did not occur until just before failure.

Only just before the rupture occurred did acoustic signals with an amplitude about 20 dB higher appear which, however, because of their number could not be evaluated statistically. However, one can assume with reasonable certainty that these acoustic signals are caused by fiber fractures since similar characteristics were found in pure tensile specimens in the work of Ahlborn [3] and Roeder [4].

In order to bring about fiber fractures in the selected test specimens at even lower total pressure loadings, in a second test series circular test specimens having a groove were employed as shown in figure 4. Such grooved laminates in which the grooves were exactly normal to the radially wound composite, failed at maximum internal pressure loadings of 400 to 600 bar. In contrast to the unscored test pieces the circular cross section increases noticeably already at pressure loads of 50 bar below the failure pressure. Such a stretching starts, with great certainty, with a continuously increasing number of fiber fractures at the groove ends since, at least in the outer cross sections, the allowable tensile stresses have been reached or exceeded. The increase in the circumference at the place of rupture was about 3%.

In the notched circular test pieces, for lower internal pressure loads, acoustic signals (figure 3) also were noted whose amplitude distribution corresponded to that described above. Above internal pressure loads of 400 to 500 bar the appearance of signals of higher intensity was indicated by a noticeable flattening of the amplitude distribution. This followed the expression $J = C \cdot D^{-n}$ with an exponent $n = 0.5$ to 0.8. A further increase of the internal pressure, following this change in the amplitude distribution, by about 50 bar led to a failure of the test specimens. Analysis of the broad-band acoustic signals made possible a further explanation of the failure mechanism.

The representation of the acoustic signals which in earlier tests were evidently caused by intermediate fiber fractures, proceeds, in a time and frequency frame, as shown in figure 5. Corresponding signals from fiber fractures as they appear just before the onset of disturbances are shown in figure 6. If we compare these signal characteristics with each other then it becomes evident that the pulses which are caused by fiber fractures are higher by about 15 dB than those which are attributed to failure of the matrix resin or to delamination. If one, on the other hand, examines the course of the frequency of the pulses, then one finds, especially at higher frequencies, a noticeably greater intensity of the signals than those observed for intermediate-fiber fractures. The observed greater intensity of the signals which presumably is caused by fiber fractures, is in agreement with the results of the amplitude analyses. It can be explained by the liberation of greater energies in the case of fiber fractures. The shape of the frequency spectrum is given by the duration of the emitted pulses. According to the theory of Fourier transforms, a short pulse corresponds to a high-frequency spectrum and a long-duration acoustic event corresponds to a rapid decay of the spectrum toward higher frequencies. If we now assume that the time for a fiber fracture compared to the time for a fracture in the matrix or for a separation of matrix and fiber is very short, then the high-frequency nature of the signals can be clearly attributed to a fiber fracture.

4. Conclusions

The acoustic emission analysis as a quasi-nondestructive test method makes it thus possible to differentiate clearly, in judging the total behavior of fiber-reinforced plastic composites, between critical failure modes - thus in the case of unidirectional composites fiber fractures - and non-critical failure modes - in this case delamination processes or matrix fractures. It is of particular advantage herein that, for varying pressure demands on the composites, the emitted acoustic pulses can be analyzed with regard to their amplitude distribution whereby it is to be recommended that this amplitude distribution be recorded at varying discriminator thresholds. In addition, definite indications as to how the damages occurred can be obtained from the time curves of the emitted acoustic pulses as well as from the particular frequency spectrum; thus distinct analogies can be drawn between the various analytical methods with respect to whether the failure modes can be classified as critical or non-critical. /91/793

5. References

1. M. A. Hamstad, Preprint UCRL - 80 - 268; Proceeding of the 24th International Instrumentation Symposium, Albuquerque, New Mexico, 1978.

2. R. v. Kloth, Batelle report of the 1. phase of the Project RS 191 to BMFT Frankfurt am Main, 1978.

3. H. Ahlborn, J. Becht and H. J. Schwalbe, Investigation of the "crack susceptibility" of different GFK laminates using the acoustic emission analysis (SEA); Kunststoffberater 6 (1975).

4. E. Roeder, H. A. Crostack and W. Brockmann, Long-time behavior of GFK (GFUP) during cyclical load demands, Kunststoffberator 6 (1975).

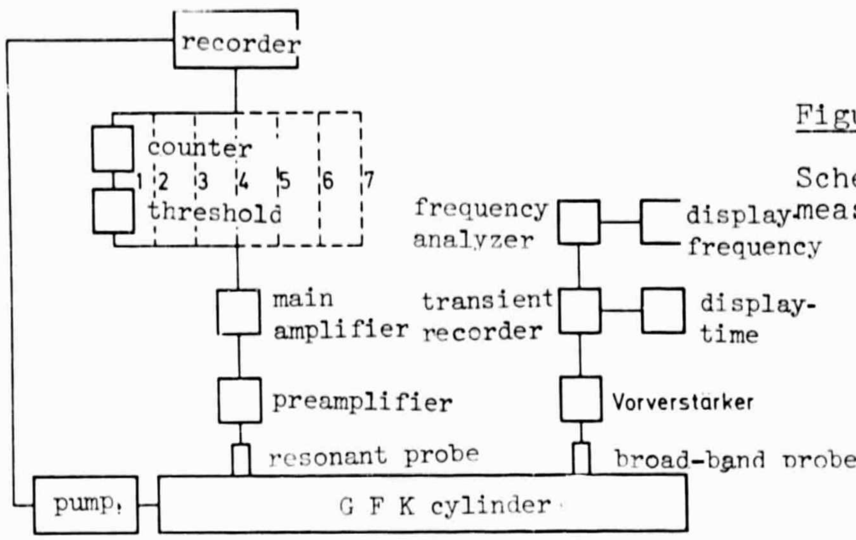

Figure 1:

Schematic of measuring installation

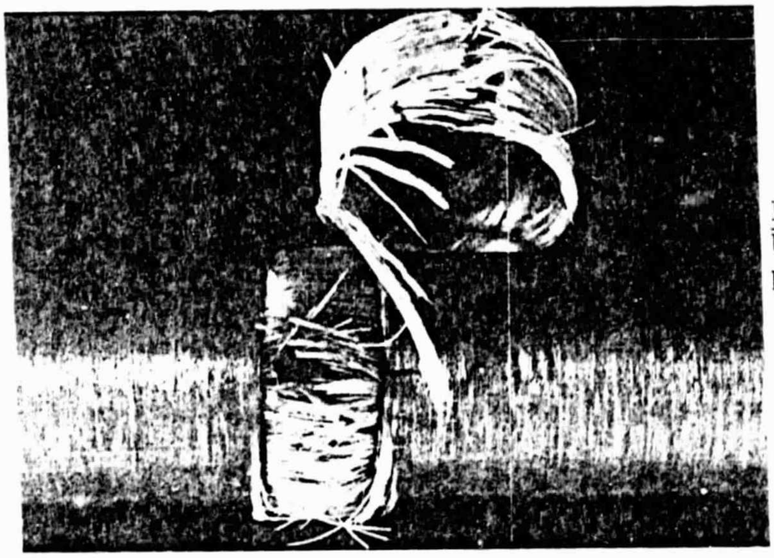

Figure 2:
Unnotched GFK tube after pressurization 1: 1.7

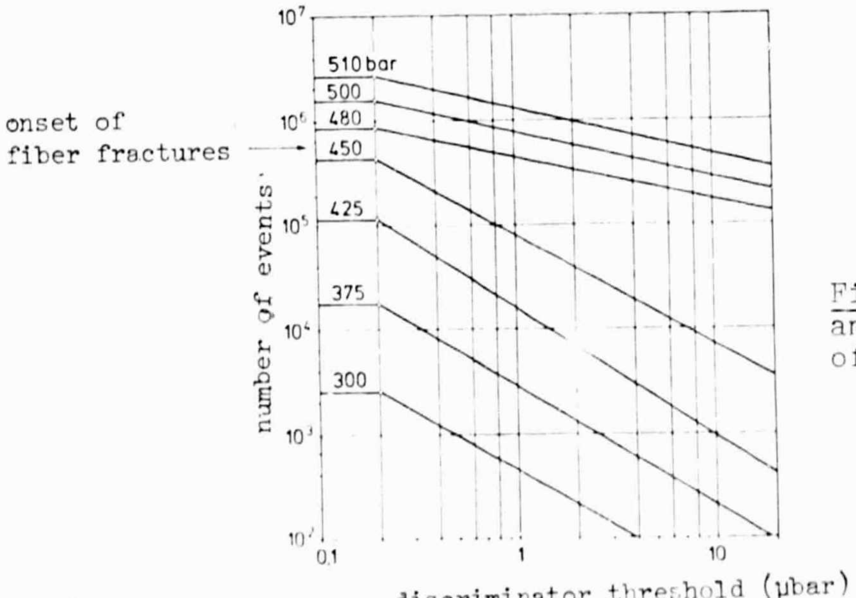

Figure 3: Cumulative amplitude distribution of the sound signals

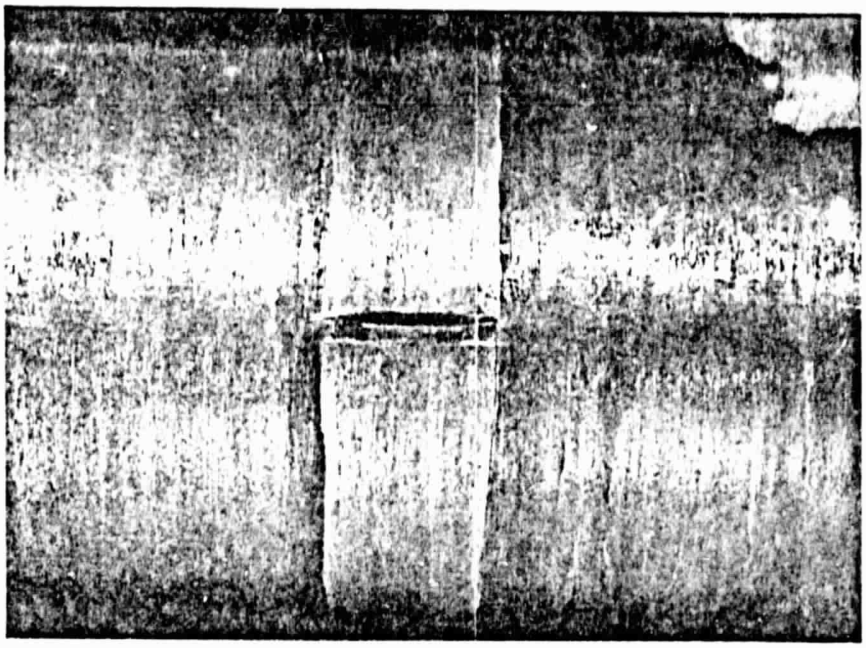

Figure 4:

Notched GFK tube after pressurization 1.4 : 1

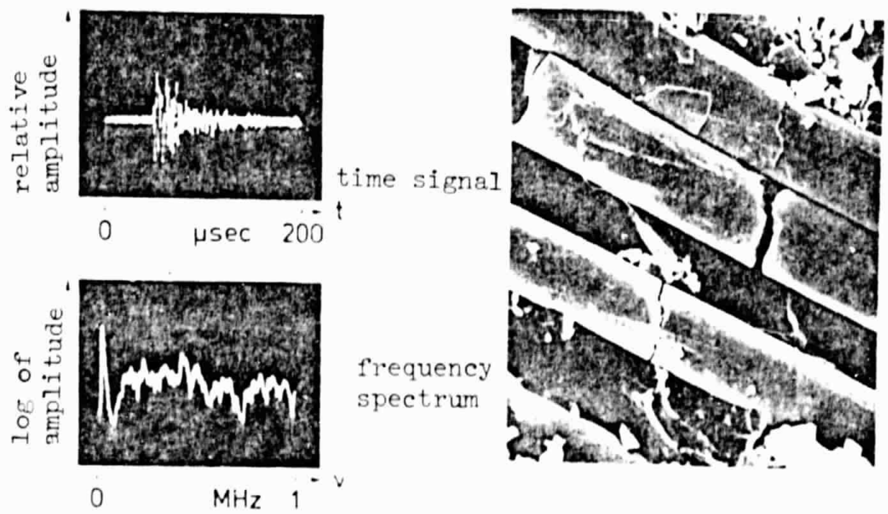

Figure 5:

Intermediate fiber fractures with accompanying SE signals REM photograph 1500: 1

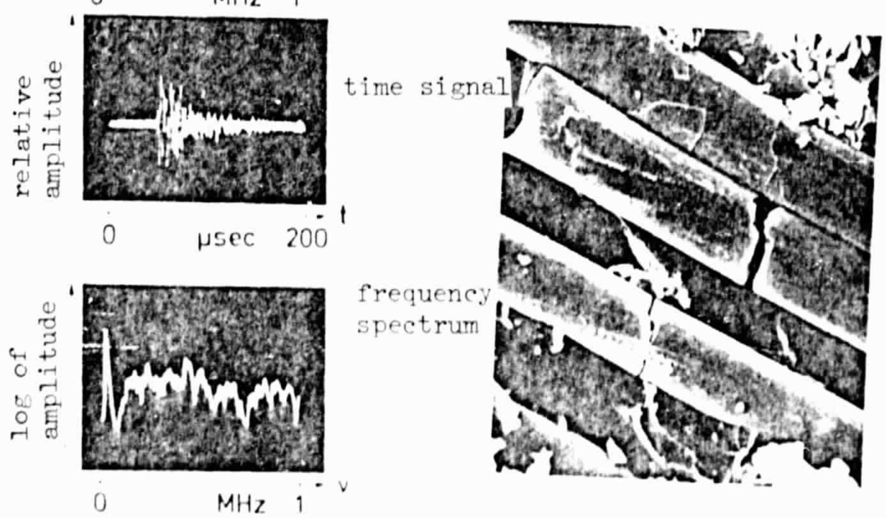

Figure 6: Fiber fractures with accompanying SE signals REM photograph 1500: 1