# ESTIMATION OF THE VISCOELASTIC PARAMETERS OF LAMINATED COMPOSITES. PART II. EXPERIMENTAL PROCEDURES

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## 1. INTRODUCTION

In order to experimentally evaluate the behavior of a viscoelastic material under sustained loading, it may be necessary to test a large number of specimens simultaneously under various loading conditions. The test program in the present study comprises isothermal testing at room as well as at elevated temperature of the different laminate systems introduced earlier. Room temperature tests were performed at 23°C and ambient humidity. The laboratory was so equipped that environmental conditions could be kept constant throughout the creep tests. Relative humidity was controlled in the room and found to be within ±5% RH. The aim is to test the material over a period of 10 hours in the laboratory, as a result of which the material parameters such as creep compliance can be measured. This information can be utilized to make a rather exact prediction of the mechanical behavior over considerably longer times of say years or even tens of years, which due to the limited experimental possibilities, is almost impossible to determine otherwise. Thus, it is important to perform tests as accurately as possible, since the results of these short time testings can be used for prediction of long time behavior through various characterization schemes such as time temperature superposition principle.

## 2. TESTING FACILITY

The creep testing facility used in the present investigation consisted of fifteen tensile testing stations with a single and seven stations with a double lever/loading arrangement having ratios of 10:1 and 25:1 respectively. Tests can be run concurrently in all stations under computer control (Figure 1 and 2). Each single lever station has a maximum working load capacity of 6 kN while that of the latter amounts to 30 kN. The loading lever system comprises three bearing positions for which the kind of bearing used is of significance. Basically, all these positions must be aligned so that the lever ratio upon deflection from the initial position remains constant. Moreover, care must be exercised in selecting the type of bearing so that friction is kept to a minimum.

The load level on the specimens is ascertained electronically. In case of single lever station for instance (Figure 1), where strain gages are applied at position K to form a full-bridge, the axial load on the test piece can be related to the bending of the lever through the output of the Wheatstone's bridge. In other words, the strain gages above the neutral axis of the lever experience a stretch when the device is loaded, while those beneath the neutral axis are compressed proportional to the applied load. For the double lever/loading arrangement (Figure 2), the applied load on the specimen is measured in a slightly different, but principally the same manner. In both cases, it is essential to ensure that the applied load remains constant and that the specimens are subjected to true axial tensile stress.

The induced creep strain e in the test piece is also measured electronically. For this purpose, one may apply conventional foil resistance strain gages directly on the specimen. To this end, either two such gages may be adhered to form a half- bridge or four gages in the form of a full bridge for more accurate and sensitive measurements. Both of the above circuits possess a certain degree of insensitivity due to the mhomogeneity and bending effects which may be present in the specimen. The full bridge version however would be more impressive in terms of strain measurements. Care must be exercised to compensate for any temperature variation that may occur.
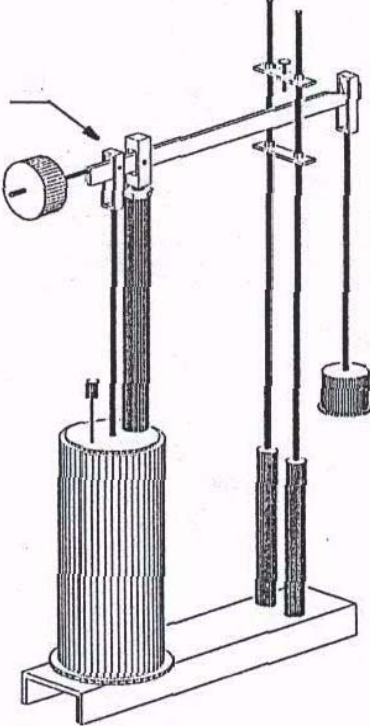


**Figure 1.** Experimental testing device - single lever arrangement
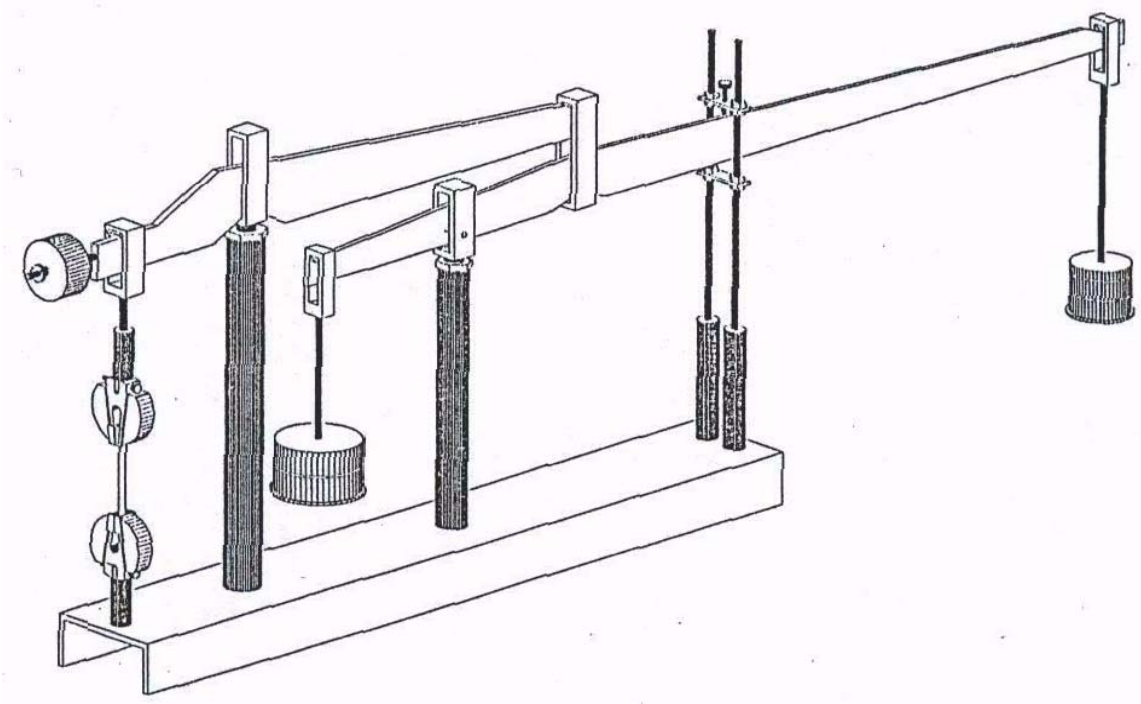


. **Figure 2.** Experimental testing device - double lever arrangement

Measurements of strain with direct use of strain gages on the specimen is however bound with some disadvantages; these arise for example from high cost of gages considering the number required, since the strain gages can only be used once, difficulties in adhering the gages on the test piece, calibration of gages, etc. Thus, it was decided to use extensometers, which may be used repeatedly and at the same time display both the sensitivity andstability requirements for accurate strain measurements throughout the duration of the testing. The principle here is to translate elongation of a denned portion of the test piece - the gage length - in a certain proportion to the bending of a thin, elastic steel plajtelet with strain gages adhered on, in the form of a full bridge. The output of such a circuit is thus a measure of the strain induced in the specimen under load. Figure 3 shows the schematic of such an extensometer with contact edges, which can be adapted to any form and/or dimension of the test piece. The V-shape arms of the extensometer serve to keep the weight of the subscriber's cable off the measuring platelet.

In practice, the extensometer with the initial length $l_0$ set prior to the begin of the test, is held in position on the specimen by two spring clamps. When the load is applied, thus elongating the specimen, the strain gages on the outer side of the platelet are compressed while those on the inner side are proportionally stretched. This in turn results in an electric signal $U_B$ which can be registered as a measure of the induced strain in the specimen.
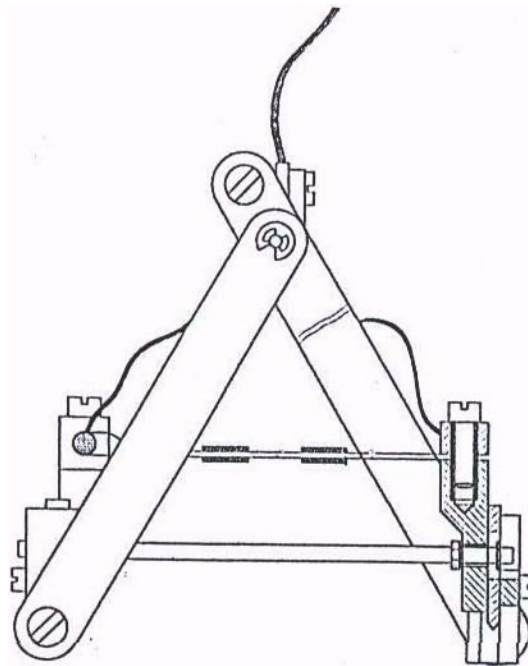


**Figure 3**. The extensometer for measurement of the strain

Conventional strain gages were applied on the [±45J2s laminates in order to measure the transverse strain $\varepsilon_y$ while the axial strain $\varepsilon_x$ was recorded with the use of the extensome-ters as described earlier. The principle of shunt calibration was applied to calibrate the transverse strain gages. The dummy gage technique was used to compensate for any thermal effect on the strain gage signal in the transverse strain measurements. This effect needs not to be considered in axial strain measurements where the strain gages of the extensometers are connected to form a full bridge circuit.
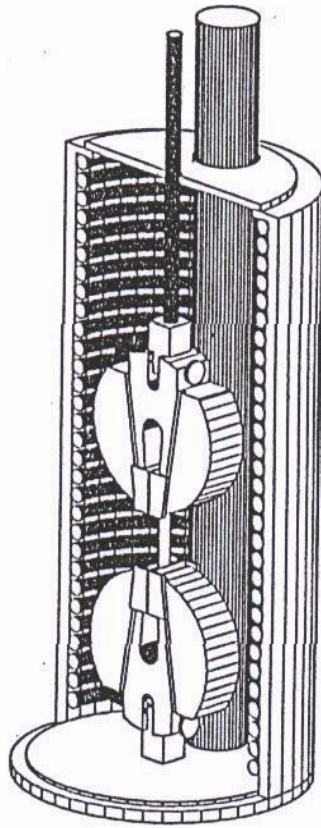
**Figure 4.** The cylindrical heating chamber for elevated temperature testing

A few of the test stations were equipped with cylindrical heating chambers for elevated temperature testing (Figure 4). Thermostatically controlled heated oil is pumped through copper coil running circumferencially through the entire length of the chambers. This results in heating up the cylindrical internal cavity of the chamber (L=360mm, D = 160mm) surrounding the specimen. The small propeller shown in Figure 1 serves to circulate the heated air inside the chamber. Temperature of the test piece was sensed using a special thermocouple applied on the specimen surface. The measured temperature inside the chamber was shown to be kept within about ±1°C.

## 3. MATERIALS AND SPECIMENS

The fiber reinforced materials investigated were commercially available composites. The epoxy resin matrix system was Fibredux 6376C (Ciba-Geigy AGJ reinforced with T800 carbon fibers (Toray Industries, Inc.). The matrix of this prepreg system is a toughened epoxy resin with a glass transition temperature of about 180°C. The thermoplastic system used was the APC-2 material (ICI). The semicrystalline PEEK matrix of this system, with a glass transition temperature of about 145°C, was reinforced with IM6 carbon fibers (Hercules, Inc.).

The laminates were manufactured using conventional techniques. The laminates of the epoxy system were cured for one hour in an autoclave at a temperature of 180°C and then postcured at 190°C for 6 hours. The PEEK system was manufactured in a press at 380°C. The quality of the molded panels was controlled by ultrasonic scanning. The fiber volume content for both systems was 60% ± 3%. The neat resin plates with a thickness of 3 mm (epoxy resin) and 4 mm (PEEK) were supplied by the resin manufacturers. The neat epoxy resin 6376 plates were subjected to the same postcuring process as the laminates. The neat thermoplastic plate (PEEK G150) was not thermally treated.

The fiber-reinforced specimens had a nominal length of 150 mm, a width of 10 mm and a thickness of 1 mm. Neat resin specimens had the same length and width as the reinforced specimens. Fiberglass end tabs were used on all specimens to avoid damaging the specimens upon clamping. It should be pointed out that the specimens were stored in desiccant filled chambers after they were fabricated. The goal

was to protect the specimens from unnecessary moisture absorption during the storage time prior to testing. The chambers showed to have a relative humidity of about 35%.

## 4. TESTING PROGRAM

As mentioned previously, isothermal creep tests were conducted at room temperature (23°C) as well as at elevated temperatures. The loading duration for each creep test was 10 hours. For both materials all the creep tests were performed at temperatures below the glass transition temperature. The maximum test temperature was about 20°C and 40°C below the glass transition temperature of the PEEK and epoxy resins, respectively. The test temperatures for PEEK were 23°, 60°, 80°, and 100°C for the neat material and 23°, 80°, 100°, and 120°C for the reinforced one. The test temperatures for the neat and reinforced epoxy samples were 23°, 80°, 120°, and 140°C.

At room temperature five stress levels ranging between 10 and 70% of the ultimate tensile stress were applied. The load levels however, were reduced with increasing test temperature. In order to assure a homogeneous temperature distribution in the specimen and in the chamber as well, tests were started one hour after the desired test temperature was reached in the chamber. Creep strains, temperature, and load were recorded at suitable time intervals during the experiments.