ASTM INTERNATIONAL

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An American National Standard

Standard Test Method for
Ambient Temperature Fatigue Life of Metallic Bonded Resistance Strain Gages[1]

This standard is issued under the fixed designation E 1949; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a uniform procedure for the determination of strain gage fatigue life at ambient temperature. A suggested testing equipment design is included.

1.2 This test method does not apply to force transducers or extensometers that use bonded resistance strain gages as sensing elements.

1.3 Strain gages are part of a complex system that includes structure, adhesive, gage, leadwires, instrumentation, and (often) environmental protection. As a result, many things affect the performance of strain gages, including user technique. A further complication is that strain gages, once installed, normally cannot be reinstalled in another location. Therefore, it is not possible to calibrate individual strain gages; performance characteristics are normally presented on a statistical basis.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 *ASTM Standards:*
E 1237 Guide for Installing Bonded Resistance Strain Gages[2]

3. Terminology

3.1 *strain gage fatigue life, n*—the number of fully reversed strain cycles corresponding to the onset of degraded gage performance, whether due to excessive zero shift or other detectable failure mode (see Section 9.6).

4. Significance and Use

4.1 Strain gages are the most widely used devices for measuring strains and for evaluating stresses in structures. In many applications there are often cyclic loads which can cause strain gage failure. Performance parameters of strain gages are affected by both the materials from which they are made and their geometric design.

4.2 The determination of most strain gage parameters requires mechanical testing that is destructive. Since gages tested for fatigue life cannot be used again, it is necessary to treat data statistically. In general, longer and wider gages with lower resistances will have greater fatigue life. Optional additions to gages (integral leads are an example) will often reduce fatigue life.

4.3 To be used, strain gages must be bonded to a structure. Good results, particularly in a fatigue environment, depend heavily on the materials used to clean the bonding surface, to bond the gage, and to provide a protective coating. Skill of the installer is another major factor in success. Finally, instrumentation systems must be carefully selected and calibrated to ensure that they do not unduly degrade the performance of the gages.

4.4 This test method encompasses only fully reversed strain cycles.

4.5 Fatigue *failure* of a strain gage may not involve visible cracking or fracture of the gage, but merely sufficient zero shift to compromise the accuracy of the gage output for static strain components.

5. Interferences

5.1 In order to ensure that strain gage test data are within a defined accuracy, the gages must be properly bonded and protected with acceptable materials. Aids in the strain gage installation and verification thereof can be found in Guide E 1237. It is important to note that good performance in cyclic applications requires the best installations possible.

6. Hazards

6.1 *Warning*—In the specimen surface cleaning, gage bonding, and protection steps of strain gage installations, hazardous chemicals are often employed. Users of these test methods are responsible for contacting manufactures of such chemicals for applicable Material Safety Data Sheets, and to adhere to the required precautions.

7. Apparatus

7.1 *Test Measurement Requirements*:

7.1.1 For fatigue life determination the uncertainty of the relative resistance change measurement shall not exceed ±5

$\mu\Omega/\Omega$ or ± 0.1 % of the actual value, whichever is greater.

7.1.2 Several methods are available for measuring the change of gage resistance with sufficient resolution and accuracy. In general, any method that is convenient may be used after it has been shown that the particular combination of instruments or components used produces a system with the required accuracy.

7.1.3 Many types of instruments are available for obtaining strain data directly from a resistance strain gage. These instruments use various types of excitation and read-out systems. Such indicators may be used only after their resolution, accuracy, and stability have been verified by connecting a resistor that can be varied in accurately known increments in place of the gage and calibrating the strain indicator over the entire range for which it will be used. The calibrating resistor steps shall be accurate to 0.1 % of the resistance change or 2 ppm of the total resistance, whichever is greater. Effects from the following influences on measurement accuracy must be quantified and found within limits that preserve the required overall system accuracy: thermal emfs within the bridge circuit and within the gage leadwire, reactive changes within the bridge and lead circuits, initial bridge unbalance, and battery conditions or power line fluctuations.

7.2 *Mechanical Equipment Requirements*:

7.2.1 A suggested cantilever test beam is shown in Fig. 1. The beam must have a fatigue life exceeding that of the strain gages to be tested. One material which meets this requirement is 3M's[3] Aerospace FP 525, which is a unidirectional glass-reinforced epoxy composite material, with all fibers aligned with the long axis of the beam. Surface spalling of metallic test beams and crazing of plastic specimens are examples of beam failures that will produce faulty, misleadingly low, strain gage fatigue life.

7.2.1.1 Beam specimens must be cut such that the glass fibers are aligned with the long dimension of the specimen. A cantilever specimen is recommended for this testing because it provides a range of strain levels in a single test. (A consequence is that the specimen's strain level near the clamp is very high. Normal structural materials will not survive such high levels and may fail in ways that imply strain gage failure when such is not the case.) A test beam should be used for one test only.

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[3] The sole source of supply of this material known to the committee at this time is 3M, Product Information Ctr., at Bldg. 515-3N-06, St. Paul, MN 55144-1000. If you aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

FIG. 1 Cantilever Test Beam

7.2.2 A suggested fatigue testing machine is illustrated in Fig. 2. For a specimen with overall dimensions as shown in Fig. 1 and a thickness of 9.5 mm (0.375 in.), the crank should deflect the beam approximately 15 mm (0.6 in.) to produce a suitable strain range from ± 500 μm/m to ± 3500 μm/m. A loading rate of 1800 cycles/min has proven efficient, but not so fast as to cause higher mode bending. While not absolutely essential, there are several features that provide for a safer and more accurate machine, as follows:

7.2.2.1 A thick plastic shield to prevent injury in case of specimen or machine failure.

7.2.2.2 A shut off device consisting of micro switches positioned above and below the specimen (near the crank) and wired in the motor power circuit to shut off power in case of specimen rupture; and

7.2.2.3 An electric counter geared to the drive system, or some other counting device appropriately connected to the machine, so the machine can be programmed to shut off or take data at preselected intervals.

8. Conditioning

8.1 *Ambient (Room Temperature) Conditions*—The nominal temperature and relative humidity shall be 23°C (73°F) and 50 %, respectively. In no case shall the temperature be less than 18°C (64°F) or greater than 25°C (77°F) and the relative humidity less than 35 % or more than 60 %.

9. Procedure

9.1 Strain levels for the test should be selected based on the expected fatigue life for the test gages. Typical values might be ± 2000 μm/m, ± 2400 μm/m, and ± 2800 μm/m. (It may be necessary to select at least one substantially lower strain level if it is desirable to indicate a no-failure strain level; see 9.6.2) Normally six or more strain gages are tested at each strain level.

9.2 *Strain Gage Attachment Requirements*:

9.2.1 The attachment conditions shall correspond exactly to the instructions published by the gage manufacturer and discussed in Guide E 1237. Most fatigue failures occur in the tab and transition areas. Use care in attaching leadwires.

9.2.2 In many applications strain gage damage will occur in the lead attachment/tab areas first. Consequently sensor survival will be enhanced by placing the solder tabs in the lowest possible strain field. When conducting fatigue tests, orient the tabs toward the low-strain end of the test beam.

9.3 The rectangular beam of Fig. 1 is convenient in providing a nearly linear strain variation from one end to the other. If it is important to test at precisely known strain levels, the beam should first be surveyed with linear strain gages to determine locations of the desired strain levels. Survey gages are placed at regular intervals along the length of the beam; installed with the major measurement axis of the gage aligned with the long axis of the beam. The beam is deflected an amount equal to the maximum test deflection and the strain levels recorded. If necessary, linear interpolation can be used to locate strain levels in between two survey gage locations. Test gages are installed with the major measurement axis of the gage aligned with the long axis of the beam at the predetermined locations. The center of the gage grid should coincide with the line of
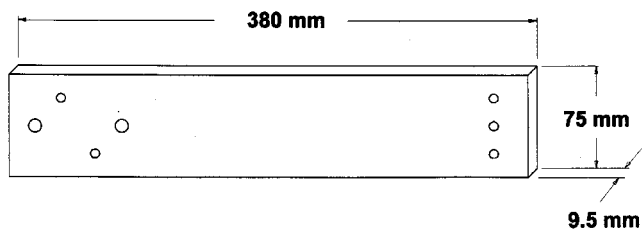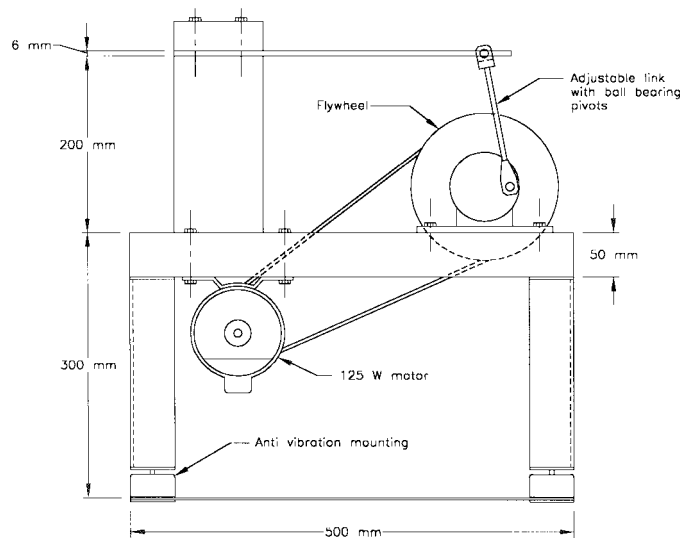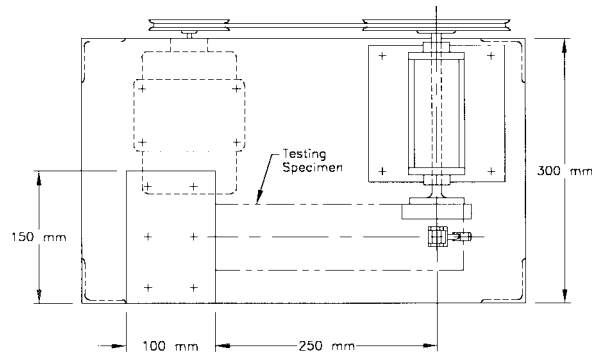
FIG. 2 Strain Gage Fatigue Rig

desired strain, as shown in Fig. 3. (Do not scribe the beam. This will produce a strain concentration within the gage grid area.) In some cases, an exact cyclic strain level is not important and test gages are installed where experience indicates the approximate desired strain is located. To achieve the most precise and consistent test results (by staying within the well defined strain area of the beam), test gages should be installed at least 50 mm (2 in.) from either the beam restraining clamp or the loading area. For best survival rate, route instrumentation leads 90 degrees from the long axis of the beam and anchor them firmly to the gage tab and beam with a suitable coating.

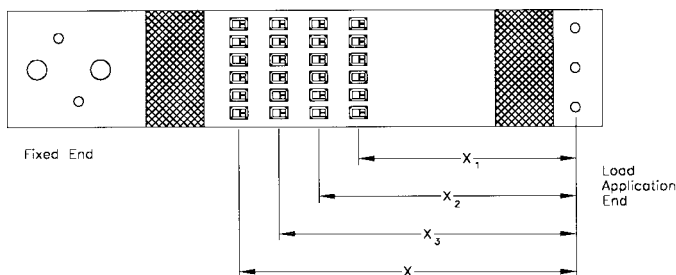9.4 The zero reading and alternating strain range for each gage must be recorded. This data can be collected either statically or dynamically. To obtain zeros statically, it is necessary to disconnect the crank arm from the specimen to remove all load from the part. The alternating strain range is then obtained by re-connecting the crank arm and rotating the drive to get maximum and minimum static strain levels. Dynamic data must be collected using an instrument with a scanning speed of at least 10 times the loading rate to prevent aliasing and possible erroneous data. The alternating strain range and zero are determined by examining 10 to 20 loading cycles. The alternating strain range is determined by calculating the difference between the mean maximum and mean minimum strains over the period. The zero is found by calculating the average of the mean maximum and mean minimum readings. Recorded data should be examined carefully to ensure that no "spikes" occur in the data which would lead to false peaks (see 9.6.1) and, therefore, false calculated zeros.

9.4.1 Regardless of data collection method (static or dynamic), all initial gage zeros should be within 50 µm/m of the midpoint of the alternating strain range.

9.5 Data should be taken at the following number of cycles: 100, 500, 1000, 10 000, 500 000, 1 000 000, 2 000 000, 5 000 000, and 10 000 000 cycles, or less if gages have failed or do not need qualification at such high cyclic lives. For static measurements, cycle the beam to the set number of cycles and

FIG. 3 Gage Layout on Fatigue Test Beam (No Gages in Cross-Hatched Areas)

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stop. Repeat the static portion of 9.4. Continue this procedure for all other set number of cycles. Conveniently, dynamic data-taking does not require stopping the machine, and the test may be run continuously with periodic checks from the operator. Ten to twenty cycles of data should be taken at each set number of approximate cycles. Continue this for all applicable number of cycles.

9.6 *Failure Criteria*:

9.6.1 Strain gages are subject to fatigue failure in three ways (other than complete rupture): (*A*) zero shift, (*B*) change in gage factor, and (*C*) *super sensitivity*. Change in gage factor is rare and, if encountered, is probably an indication of faulty strain gages under test. *Super Sensitivity* can be seen by monitoring gage output on an oscilloscope during dynamic cycling. It is caused by the onset of grid cracking and the symptom is the occurrence of spikes at the top of the tension cycle (on the wave form). Again, super sensitivity is a relatively rare occurrence until long after gages have failed the zero shift test.

9.6.2 The standard level of zero shift defining strain gage failure is 100 μm/m. At this level strain gages rarely exhibit appreciable gage factor change or super sensitivity. Laboratories using this test method may elect to assign a higher value for zero shift failure but must clearly indicate doing so. A typical case when a higher standard level of zero shift failure might be selected is that of isoelastic strain gages, used primarily for dynamic testing. For such gages a standard level of zero shift failure of 300 μm/m is often chosen. However, as the testing laboratory raises its standard level of zero shift

failure, gage factor change and super sensitivity become increasingly likely as failure modes.

10. Report

10.1 The measured data should be presented in tabular format as part of the report.

10.2 Data may be presented graphically; an example is shown in Fig. 4. The dashed lines in Fig. 4 are optional. They may be omitted or a different shape (such as a hyperbola) may fit data better. If properly drawn, the line(s) will represent the level at which approximately 50 % of gages will fail in any test.

10.3 As the test strain is lowered and the number of cycles increased, the range of failure points at a single strain level is likely to increase markedly. At high cycle fatigue (over 500 000 cycles) ranges of 10:1 and greater are not unusual.

10.4 In order to plot the horizontal *No Failure* line there must be at least one strain level in the test (see 9.1) such that test gages at it do not fail at the maximum number of test cycles.

10.5 *Precision*—No precision statement based on interlaboratory testing is possible at this time. Committee E28 is not aware of sufficient laboratories to conduct an appropriate program of testing but seeks cooperation of any and all laboratories concerned with implementing these test methods. The committee is willing to coordinate such an activity.

10.6 *Bias*—Since there are no reference or true values of strain gage performance characteristics, no bias estimates can be measured.
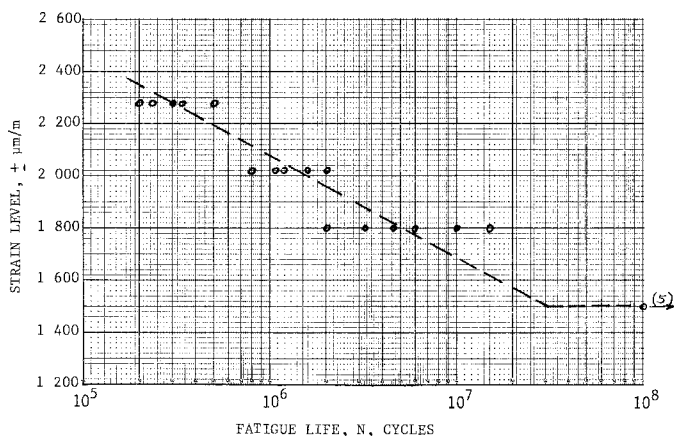
NOTE 1—Typical strain gage fatigue life curve.
FIG. 4 Data points represent failure of gages.