Designation: D 671 – 93

Standard Test Method for Flexural Fatigue of Plastics by Constant-Amplitude-of-Force[1]

This standard is issued under the fixed designation D 671; 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 the determination of the effect of repetitions of the same magnitude of flexural stress on plastics by fixed-cantilever type testing machines, designed to produce a constant-amplitude-of-force on the test specimen each cycle.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety problems, 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 use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 4000 Classification System for Specifying Plastic Materials[3]

3. Summary of Test Method

3.1 This test method measures the ability of a material to resist deterioration from cyclic stress. The test results provide data on the number of cycles of stress to produce specimen failure by fracture, softening, or reduction in stiffness by heating as a result of internal friction (damping).

4. Significance and Use

4.1 The flexural fatigue test provides information on the ability of rigid plastics to resist the development of cracks or general mechanical deterioration of the material as a result of a relatively large number of cycles of constant amplitude of force.

4.2 This test method is useful to determine the effect of variations in material, stress, and environmental conditions on the ability of a material to resist deterioration resulting from repeated stress. It may also be used to provide data for use as a guide to design and selection of materials for service under conditions of repeated stress.

4.3 The results are suitable for direct application in design only when all design factors including magnitude and mode of stress, size and shape of part, ambient and part temperature, heat transfer conditions, cyclic frequency, and environmental conditions are comparable to the test conditions.

4.4 The results obtained from testing machines other than the type described here may not agree due to differences in specimen size and geometry, testing machine speeds, heat transfer, material fabrication, etc.

4.5 The type of machine covered in this test method is suitable for determining the fatigue strength for a range of mean stress in flexure. However, for plastic materials, which creep and stress relax, the effect of a mean stress other than zero is to cause relaxation so that the stress cycle tends to approach the condition of complete reversal of stress.

4.6 Tests of thin sheet yield results which vary with the thickness of the sheet (Note 1). Because of this fact the thickness of the sheet shall be specified when reporting results of tests of thin sheet; and all comparisons of different materials, or selection of materials on the basis of fatigue strength, shall be made from results of tests of standard specimens or tests in which the same thickness of sheet is used for all materials.

NOTE 1—For the purposes of this test a thin sheet shall be defined as a sheet less than 7.6 mm (0.3 in.) in thickness or a material for which the ratio of the modulus of elasticity to the fatigue limit is less than 100. The reason for these restrictions is that thin sheets and materials having a low modulus of elasticity are bent so much under the required loads that the fatigue specimen cannot (in the deflected position) be considered a straight beam and hence the following equation is not accurate:

$$S = Mc/I$$

where:

S = stress in outer fiber,
M = bending moment (PL),
c = distance from neutral axis to outer fiber, and
I = moment of inertia.

[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 08.03.

4.7 In any plastic part fatigue may be frequency dependent. Data should not be extrapolated to other frequencies unless the frequency response is known.

4.8 In any plastic having appreciable damping, fatigue is dependent on the heat transfer of the specimen or part to the surroundings. Changes in testing temperature, test frequency, rate of removal of heat (as by current of air from a fan) will affect test results. It may be desirable to measure the effect of these variables or combinations thereof to more closely simulate end-use conditions for some specific application.

4.9 The nominal stress or strain resulting from the applied load does not always represent the actual magnitude of the applied stress or strain at the test section of the specimen. The elementary beam formula will not yield precise results for materials whose: (*a*) stress-strain relationship is not linear, (*b*) stress-strain curve in tension is not identical to that in compression, or (*c*) internal damping is large. Most plastics have one or more of these characteristics. No generally satisfactory method of taking these factors into account is yet available.

4.10 For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 of Classification System D 4000 lists the ASTM materials standards that currently exist.

5. Apparatus (Fig. 1)

5.1 *Testing Machine*—A fatigue testing machine of the fixed-cantilever, repeated-constant-force type[4] (see Appendix X1). In this machine the specimen, *A*, shall be held as a cantilever beam in a vise, *B*, at one end, and bent by a concentrated load applied through a yoke, *C*, fastened to the opposite end. The alternating force shall be produced by an unbalanced, variable eccentric, *D*, mounted on a shaft. The shaft shall be rotated at constant speed by a motor.

5.2 *Counter*—A counter, *E*, to record the number of cycles.

5.3 *Cut-off Switch*—A suitable mechanically or electrically operated cut-off switch, *F*, shall be provided to stop the machine when the specimens fail.

5.4 *Thermometer*—A suitable means of measuring the specimen temperature during the fatigue test such that the fatigue stress is not disturbed. One approach which has been successful utilized a radiation thermometer[5] to measure the specimen surface temperature. Other approaches such as adhering thermocouples to the specimen surface may be adequate provided the stress distribution in the fatigue experiments is not disturbed.

6. Test Specimens

6.1 The test specimens shall conform to one of the two geometries (Type A or Type B) shown in Fig. 2. Selection of a particular specimen will depend upon specimen thickness and

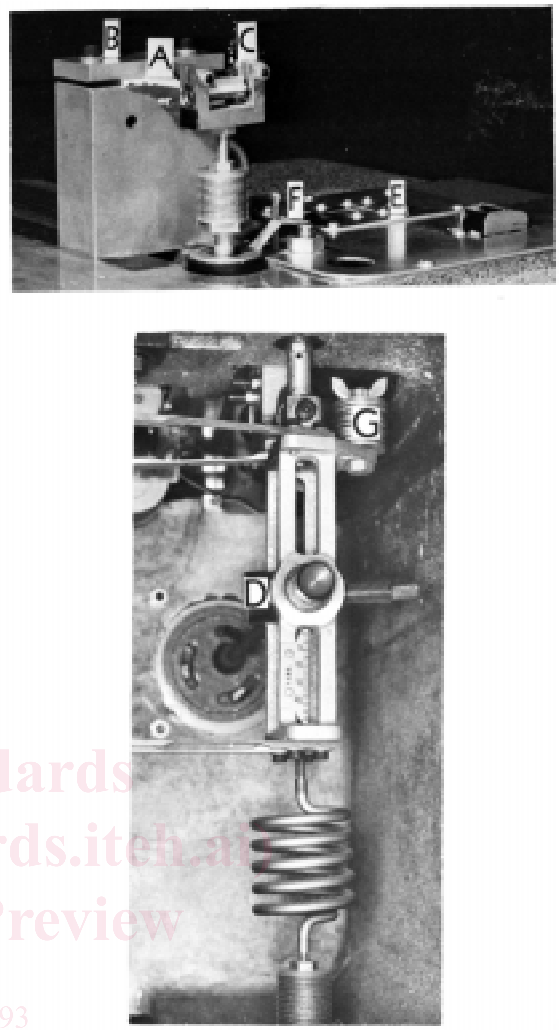

FIG. 1 Fixed-Cantilever, Repeated-Constant-Load Type Fatigue Testing Machine

the stress range over which the measurements are to be made. The triangular form of these specimen types provides for uniform stress distribution over their respective test spans.

6.2 Machining of each specimen shall be accomplished with a very sharp cutting tool, using such combination of speed and feed as will give a good finish with a minimum of heating of the specimen. The test specimen shall be polished with successively finer emery paper, finishing with No. 00 to remove all scratches and tool marks. The final polishing shall be lengthwise of the specimen, since even small scratches transverse to the direction of tensile stress tend to lower the fatigue strength. In order to avoid heating, all polishing shall be done either by hand or with light pressure on a slowly revolving sanding drum. Care shall be taken to avoid rounding the edges and corners of the specimen.

6.3 Specimens may be molded to the dimensions specified in Fig. 2, but care should be taken to stress relieve internal stress unless the effect of molded-in stress is to be measured.

7. Conditioning

7.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less

[4] Model SF-2U Constant-Amplitude-of-Force Fatigue Machine, available from Satec Systems, Inc., Liberty St. Extension, Grove City, PA 16127, has been found satisfactory for this purpose.

[5] Ircon Radiation Thermometer Series 700, available from Ircon Inc., 207 Lawrence Rd., Niles, IL, has been found satisfactory for this purpose.

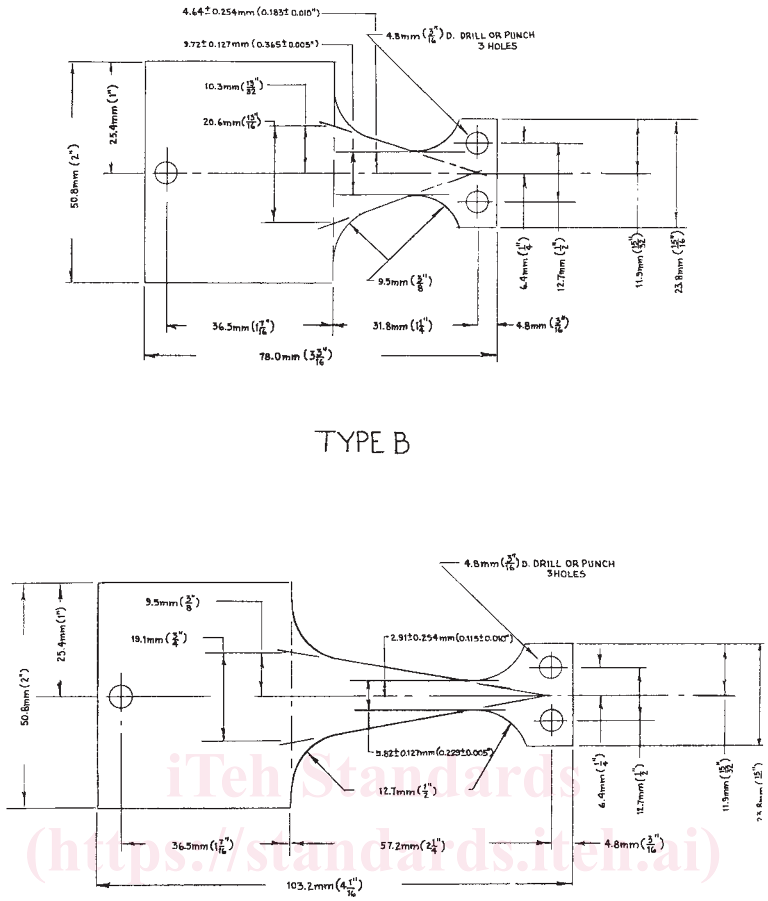

FIG. 2 Dimensions of Constant Force Fatigue Specimens

than 40 h prior to test in accordance with Procedure A of Practice D 618, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ± 1°C (±1.8°F) and ±2 % relative humidity.

7.2 *Test Conditions*—Conduct tests in the Standard Laboratory Atmosphere of 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified in the test method. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

7.3 The mechanical properties of many plastics change rapidly with small changes in temperature. Since heat is generated as a result of the flexing of the specimen, tests shall be conducted without forced cooling to ensure uniformity of test conditions. The temperature at the region of the highest stress in the specimen shall be measured and recorded.

7.3.1 When the effect of heat transfer is being measured, it is acceptable to cool the test specimen to simulate end use conditions. However, it should be realized that heat transfer is undoubtedly the most difficult variable to simulate or control. To develop fatigue data under refrigeration or at isothermal conditions is only of value if the material will be used under similar conditions. Artificial cooling shall not be used to force the material to fail mechanically when thermal failure is the controlling mechanism in the application.

8. Procedure

8.1 *Tuning Machine*—Tune machine by using a thin metal specimen having a natural frequency of 1800 ± 4 cpm when vibrating as a free cantilever beam. (Tuning specimens and weights are furnished by the manufacturer of the test apparatus.) Tune by the following procedure:

8.1.1 Set the eccentric, *D*, Fig. 1, very near zero load, that is, at about 0.1 to 0.3 units. Do not change this setting during subsequent tuning runs (tests).

8.1.2 Make several runs of a minute or two each, using different total tuning weights, *G*, Fig. 1, and plot the total tuning mass versus the amplitude of vibration to the nearest 0.5 mm (0.02 in.). At low values of mass the amplitude will be very small, increasing to higher values as proper tuning is reached by the addition of more weights. Further addition of mass will then result in a decrease of amplitude.

8.1.3 Select the proper tuning mass (to the nearest 0.02 % of the dynamic machine capacity) from the peak of the mass-versus-amplitude curve. This value is a constant for the machine and is called the "complementary mass."

8.2 *Measurements*—Test three or more specimens at each of at least four different stress amplitudes. Choose stress amplitudes to yield a mean log of cycles to failure (log *N*) of about

4, 5, 6, and 7. Measure the minimum thickness of the triangular portion of each specimen to the nearest 0.03 mm (0.001 in.). Clamp the specimen snugly in the vise, *B*, Fig. 1, with its smaller end screwed securely to the vibrating yoke, *C*. Measure the test span, *L*, to the nearest 0.5 mm (0.02 in.) from the leading edge of the vise, *B*, along the principal axis of the specimen to the line-of-centers of the mounting screws in the yoke, *C*. Measure the width, *b*, of the specimen defined by the intersection of the leading edge of the vise with the sides (or projections thereof) of the triangular portion of the specimen, to the nearest 0.3 mm (0.01 in.).

8.3 *Calculation of Effective Mass of Test Specimen*—Calculate the effective mass (Note 2) of the standard specimen Types A and B (Fig. 2) as follows:

For Type A Specimen:

$$W = kDd$$

For Type B Specimen:

$$W = k'Dd$$

where:

W = effective mass, g (or lb),
D = density of the specimen (material), Gg/m^3(or lb/in.^{3}),
d = average specimen thickness, mm (or in.),
k = 248 mm^2(0.385 in.^{2}), and
k' = 323 mm^2(0.50 in.^{2}).

NOTE 2—The "effective mass" of a given specimen is best understood as follows: Consider an actual cantilever specimen and then another "ideal" specimen of the same bending stiffness, but which is weightless along its stressed length. Let a concentrated mass be applied to the free end of the ideal specimen. If this concentrated (lumped) mass produces in this specimen the same transverse inertial force as the total transverse inertial forces associated with a test specimen vibrating at the same amplitude and frequency, then this concentrated mass is equal to the effective mass of the test specimen.

8.4 *Attachment of Tuning Weights*—Determine the proper amount of tuning weights, *G*, Fig. 1, by subtracting the effective mass of the test specimen, as determined in 8.3, from the complementary mass of the machine, determined in 8.1. Add these tuning weights to the vibrating assembly of the testing machine.

8.5 *Calculation of Test Load*—Calculate the load to be applied to the specimen from the desired (known) alternating stress as follows:

$$P = Sbd^2/6L$$

where:

P = load, N (or lbf), to be applied to the specimen,
S = desired alternating stress, MPa (or psi),
b = specimen width, mm (or in.),
d = specimen thickness, mm (or in.), and
L = test span, mm (or in.).

The load, *P*, required to produce the desired stress, *S*, in the specimen is then set on the eccentric, *D*, Fig. 1.

8.6 *Frequency of Testing*—Response of plastics to load is time dependent; therefore, fatigue tests should be conducted at the frequency of interest. However, the equipment described in this test method is designed to operate at 30 Hz and changing the frequency requires changing the drive unit and the spring-mass system so that tuning (see 8.1) can be achieved. When frequency is not specified, tests shall be conducted at 30 Hz ± 5 %.

8.7 *Readings*—Set the revolution counter at zero before starting a test. Upon failure of the test specimen, read the counter to determine the number of cycles to failure.

8.8 *Temperature Measurement*—Measure the steady-state temperature. If steady-state conditions do not occur, measure the temperature throughout the fatigue test. In all fatigue tests, measure the temperature at failure unless it can be shown that the heat rise is insignificant for the specific material and test condition. Focus the radiation thermometer on the expected failure area of specimen. Temperature measurements should be measured over small areas, such as over a 1-mm (0.040-in.) diameter spot, and the specimen should be periodically scanned to ensure that the maximum localized heating is being measured.

9. Plotting and Interpreting Results

9.1 *Plotting Results*—Plot an *S-N* (stress versus cycles-to-failure) diagram with the alternating stress amplitude as the ordinate against the common logarithm of the number of cycles required for failure (see X3.21) as the abscissa. Plot all test data and define the *S-N* diagram preferably using a regression analysis or by drawing the best-fit smooth curve as closely as possible through the points. The use of semilogarithmic paper will facilitate the plotting. Indicate on the diagram specimens that did not fracture by an arrow directed away from the plotted point in the direction of increasing cycles.

9.1.1 When a sufficiently large number of samples are tested at a given stress level, probability plots of fatigue life at the given stress are useful to determine the F_{50} fatigue life at that stress. The F_{50} values at various stress levels may then be used to define the *S-N* diagram.

9.2 *Interpretation of Results*—When a material shows a knee in the *S-N* or stress-cycle diagram such that the curve gives clear indications that it becomes asymptotic to a horizontal (constant-stress) line, it is sufficient to carry the number of cycles far enough beyond the knee to indicate with a good degree of accuracy that the curve becomes asymptotic to a constant-stress line. If the curve does not become asymptotic to a constant-stress line, continue the test until the number of cycles reached is greater than the number of cycles that the material will be expected to withstand in its life. Report the value of the alternating stress amplitude corresponding to this number of cycles as the" fatigue" strength at the maximum number of cycles for which the stress-cycle diagram has been well defined by the tests.

10. Report

10.1 Report the following information:

10.1.1 Description of the material tested, including name, manufacturer, code number, date of manufacture, type of molding, and thickness of specimen or original material in case of thin sheet,

10.1.2 Dates of the test,

10.1.3 Model of testing machine,

10.1.4 Size and type of specimen,

10.1.5 Thickness of the specimen in the case of thin sheets,