Standard Test Method for Shock Attenuating Properties of Materials Systems for Athletic Footwear[1]

This standard is issued under the fixed designation F 1614; 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 measurement of certain shock attenuating characteristics, rapid rate force-displacement relationships, of materials systems employed in the midsole of athletic footwear intended for use in normal running movements. This test method covers three different procedures for performance of the rapid rate force application: Procedure A for falling weight impact machines, Procedure B for compression force controlled machines, and Procedure C for compression displacement controlled machines.

1.2 The material system response for rapid rate force application may be different for each of the three procedures of this test method.

1.3 This test method is empirically based on the use of an 8.5-kg mass dropped from 50 mm (1.97 in.) to generate peak compressive forces which are comparable to that experienced by a midsole in heel strike tests for normal running movement.[2,3] This requires the specimen to be rigidly supported and the energy to be delivered through a 45-mm (1.8-in.) diameter flat tup.

1.4 This test method imposes an impulse to generate a rapid rate compressive force-displacement hysteresis cycle and evaluates shock attenuating characteristics of the specimen. The maximum energy applied to the specimen occurs at peak displacement and must be within ±10 % of a reference value that is used to normalize the data for comparative purposes.

1.5 Shock attenuating characteristics, for this test method, are in terms of absorbed energy loss during the hysteresis cycle, peak pressure, maximum strain, and average stiffness. Each of these characteristics will have varying importance, depending on the design objectives for the material system in the athletic footwear product.

1.6 Test results obtained by this test method shall be qualified by the specimen thickness and the reference maximum energy applied.

1.6.1 Nominal specimen thickness values for this test method are in the range from 5 to 35 mm (0.2 to 1.4 in.), see 7.1.

1.6.2 The standard value for the reference maximum energy applied of this test method is 5.0 J. Other values may be used, if they are clearly stated in the report.

NOTE 1—For Procedure A, the use of a 8.5-kg mass and an initial distance of 50 mm between tup and specimen will produce the required impulse and result in maximum energy applied values in the range of 5 ± 0.5 J (44.2 ± 4.4 in.-lb), depending on specimen thickness and material response.

NOTE 2—For Procedures B and C, the required impulse is produced by having the maximum energy applied within the range of ±10 % of the reference value (5 J, see 1.6.2) and the time to peak controlling variable (force or displacement) being 15 ± 5 ms.

NOTE 3—There is no evidence to support comparisons of data for tests which used either different reference maximum energy applied values or for Procedure A, different mass and drop height conditions.

NOTE 4—Applications involving more vigorous (for example, basketball) use of athletic shoes may require shock absorption tests which utilize larger reference impulse values to generate comparable compressive force hysteresis cycles.

NOTE 5—Shock attenuation is strongly dependent on specimen thickness. This test method can be used to identify the effects of thickness variations on shock attenuating properties of midsole materials and athletic footwear products, see 7.2.

NOTE 6—Comparisons of different material systems by this test method should take careful consideration of prior impact conditioning. The ability of footwear materials to attenuate shock tends to decrease with repeated impact.[2]

1.7 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

1.8 *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 use.*

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[1] This test method is under the jurisdiction of ASTM Committee F-8 on Sports Equipment and Facilities and is the direct responsibility of Subcommittee F08.54 on Footwear.

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[2] Misevich, K. W. and Cavanagh, P. R., "Material Aspects of Modeling Shoe/Foot Interaction," *Sports Shoes and Playing Surfaces*, (E. C. Frederick, ed), Human Kinetics: Champaign, Illinois, 1982, pp. 47–75.

[3] Denoth, J., "Load on the Locomotor System and Modeling," Chapter 3, *Biomechanics of Running Shoes*, (B. M. Nigg, ed.), Human Kinetics: Champaign, Illinois, 1986, pp. 63–116.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[4]

D 3763 Test Method for High-Speed Puncture Properties of Plastics Using Load and Displacement Sensors[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

F 355 Test Method for Shock-Absorbing Properties of Playing Surface Systems and Materials[7]

F 869 Definitions of Terms Relating to Athletic Shoes and Biomechanics[7]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *acceleration*—the time rate of change of velocity.

3.1.2 *accelerometer*—a transducer for measurement of the acceleration of the impact mass.

3.1.3 *compression cycle*—the complete impact event of increasing displacement and decreasing displacement.

3.1.4 *displacement*—the linear motion of the tup during impact force application. Synonymous with deflection.

3.1.5 *dynamic—in this standard*, refers to events which occur with durations of approximately 0.005 to 0.05 s.

3.1.6 *energy*—the capacity for doing work and overcoming resistance. The energy of the test machine is used for the work of specimen displacement. Measured as the integral of force with respect to the distance through which the force is exerted.

3.1.7 *force*—the reaction of the resistance of a object to displacement or motion, or both. The interaction between test machine and specimen during compression displacement is represented as a force. Synonymous with load.

3.1.8 *g*—the ratio of the magnitude of impact mass acceleration to the gravitational acceleration constant, expressed in the same units.

3.1.9 *gravity driven*—motion is controlled by the gravitational forces, as for the dropping of the impact mass.

3.1.10 *hysteresis*—the force takes on different values for increasing displacement than for a decreasing displacement.

3.1.11 *hysteresis energy*—the energy loss during the compression cycle.

3.1.12 *hysteresis energy ratio*—the ratio (HER) of hysteresis energy to the maximum energy applied.

3.1.13 *impact*—a dynamic contact interaction between two solid bodies. *In this standard*, refers to force interactions within the time range from 0.005 to 0.05 s.

3.1.14 *impulse*—the change in momentum effected by a force. Measured as the product of force and the time over which the force is exerted.

3.1.15 *load*—synonymous with force.

3.1.16 *mass*—a fundamental unit of measure (units are kilograms) that is independent of the specific gravitational acceleration constant (g). See *weight*.

3.1.17 *maximum energy applied*—this is the energy applied to the specimen at maximum compression displacement.

3.1.18 *pressure*—the ratio of force to the transverse cross-sectional area of the tup.

3.1.19 *rigid*—a relative term used here to identify an impact condition for which the previously stationary object has minimal or insignificant displacement as a result of the collision by the moving object.

3.1.20 *shock*—a short duration high force part of an impact.

3.1.21 *shock attenuation*—the reduction of peak force with the increase of the time over which the force is applied.

3.1.22 *stiffness*—the resistance to displacement. Measured as the ratio of force to displacement.

3.1.23 *average stiffness*—the ratio of peak force to the corresponding displacement.

3.1.24 *strain*—the ratio of displacement to specimen thickness.

3.1.25 *transducer*—a measurement device which senses the physical quantity of interest and generates an electrical signal in proportion to its magnitude.

3.1.26 *tup*—leading surface of moving portion of test machine in contact with specimen during the impact cycle.

3.1.27 *velocity*—the speed or time rate of change of displacement, for the test machine tup.

3.1.28 *weight*—the measure of mass (m) that is relative to the gravitational acceleration constant (g). Weight = mg. The 8.5-kg mass (m) has a weight of 83.27 N (18.72 lb) at g = 9.81 m/s^2 (32.17 ft/s^2).

4. Summary of Test Method

4.1 A test specimen is loaded in compression at a rapid rate which, because of the method of force application, is different for each of the three procedures. The specimen is supported on a rigid foundation and force is applied through a circular flat face of 45-mm (1.8-in.) diameter. Force and displacement transducers are employed for measurement of the complete loading and unloading compression cycle. Procedure A provides for optional determination of specimen displacement by calculation.

4.2 The three procedures covered by this test method have a common requirement for the maximum energy applied to be within ±10 % of a standard reference value of 5 J (44.2 in.-lb). Other reference energy values may be used, if they are clearly stated in the report (see 1.3 and Note 3).

4.2.1 Procedure A uses gravity-driven impact of an 8.5-kg mass as the method for force application. The impact velocity and resultant rate of force application are determined by a standard drop height (50 mm). The maximum force, maximum displacement, and maximum energy applied to the specimen are determined by the inherent shock attenuation characteristics of the material system. The maximum energy applied to the specimen (*UM*) is usually in the range from 4.5 to 5.5 J (39.8 to 48.7 in.-lb), depending on specimen displacement (*DM*).

NOTE 7—For Procedure A, typical values for *UM* at *DM* are:

DM (mm)	UM (J)
5	4.6
10	5.0
15	5.4

[4] *Annual Book of ASTM Standards*, Vol 08.01.
[5] *Annual Book of ASTM Standards*, Vol 08.02.
[6] *Annual Book of ASTM Standards*, Vol 14.02.
[7] *Annual Book of ASTM Standards*, Vol 15.07.

4.2.2 Procedure B uses hydraulic, pneumatic, or screw-driven machines to apply a preselected force function, through a machine control process. This function is adjusted to have the time to reach peak force be in the range of 15 ± 5 ms. The maximum displacement and maximum energy applied to the specimen are determined by the selected force level and the inherent shock attenuation characteristics of the material system of the test specimen. The force is selected to yield maximum energy applied to the specimen in the range from 4.5 to 5.5 J (39.8 to 48.7 in.-lb).

4.2.3 Procedure C uses hydraulic, pneumatic, or screw-driven machines to apply a preselected displacement function, through a machine control process. This function is adjusted to have the time to reach peak displacement be in the range of 15 ± 5 ms. The maximum force and maximum energy applied to the specimen are determined by the selected displacement level and the inherent shock attenuation characteristics of the material system. The displacement is selected to yield maximum energy applied to the specimen in the range from 4.5 to 5.5 J (39.8 to 48.7 in.-lb).

5. Significance and Use

5.1 This test method is used by athletic footwear manufacturers both as a tool for development of midsole material systems and as a test of the general characteristics of the athletic footwear product (see 1.4-1.6.2 and Notes 1-6). Careful adherence to the requirements and recommendations of this test method shall provide results which can be compared between different laboratory sources.

5.2 Dynamic data obtained by these procedures are indicative of the shock attenuating properties (see 1.5) of the material systems under the specific conditions selected.

5.3 This test method is designed to provide force versus displacement response of materials systems for athletic footwear under essentially uniaxial compression conditions at impact rates, which are similar to that for heel strike in normal running movements.[2,3] That is, peak forces of up to 2 kN (450 lb) in times of 10 to 20 ms.

5.4 The peak or maximum values of force, pressure, displacement, and strain are dependent on the maximum energy applied to the specimen. These values are normalized to provide comparative results for a reference maximum energy applied to the specimen of 5 J.

5.5 Shock attenuating characteristics are strongly dependent on specimen thickness and prior history of force application. Therefore, results should be compared only for specimens of essentially the same thickness and prior impact conditioning (see Notes 3-6). There are no currently acceptable techniques for normalizing results for specimen thickness variations.

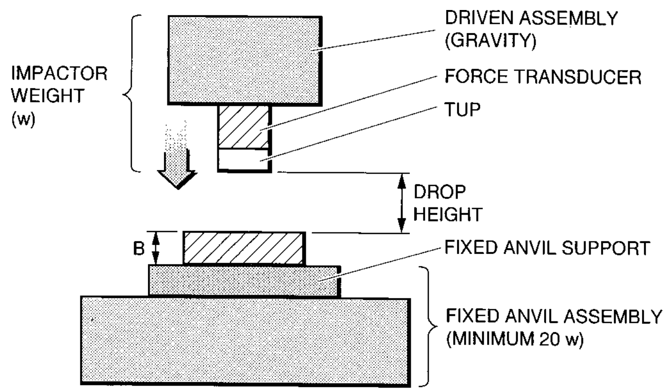
5.6 Shock attenuating values (see 1.5) determined by this test method, for materials systems of athletic footwear, may not correlate with the similar values experienced by a runners heel or foot.

6. Apparatus

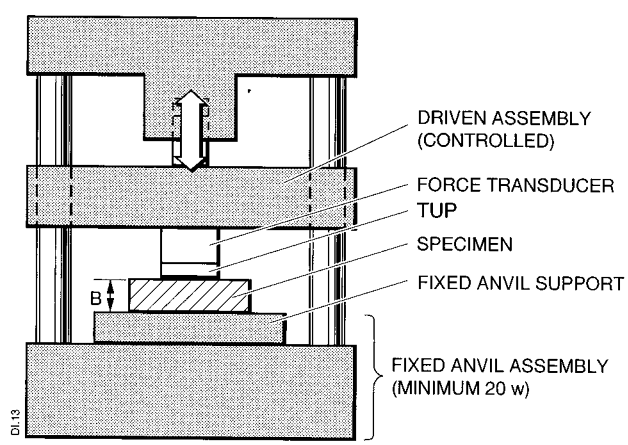
6.1 The testing machine shall consist of two assemblies, one fixed and the other driven by a suitable method to achieve the required maximum energy applied to the specimen and loading time (that is; hydraulic, pneumatic, mechanical, or gravity), see Fig. 1. Procedure A results in a maximum energy applied to the specimen through use of a specific mass dropped from a specific height. Procedures B and C require the apparatus to impose a displacement which results in a maximum energy applied to the specimen of 5.0 ± 0.5 J (44.2 ± 4.4 in.-lb) with the time to reach peak displacement being 15 ± 5 ms.

6.1.1 *Fixed Anvil Assembly*, consisting of flat rigid plate with elastic cords (or equivalent) for holding specimen in position during multiple impacts. This specimen support shall be normal to the direction of force application, and have a geometry which provides complete contact with the bottom of the specimen over an area which is at least as large as a 76-mm diameter circle. This support area shall be centered beneath the tup of the driven plunger assembly (see 6.1.2 and Fig. 2). Rigid is in reference to the physics of momentum transfer.

6.1.1.1 *Procedure A*—For the impact conditions of Procedure A, rigid can be achieved by having the fixed anvil assembly have a mass which is at least twenty times greater



a. Procedure A.



b. Procedure B or C.

FIG. 1 Mechanical Apparatus

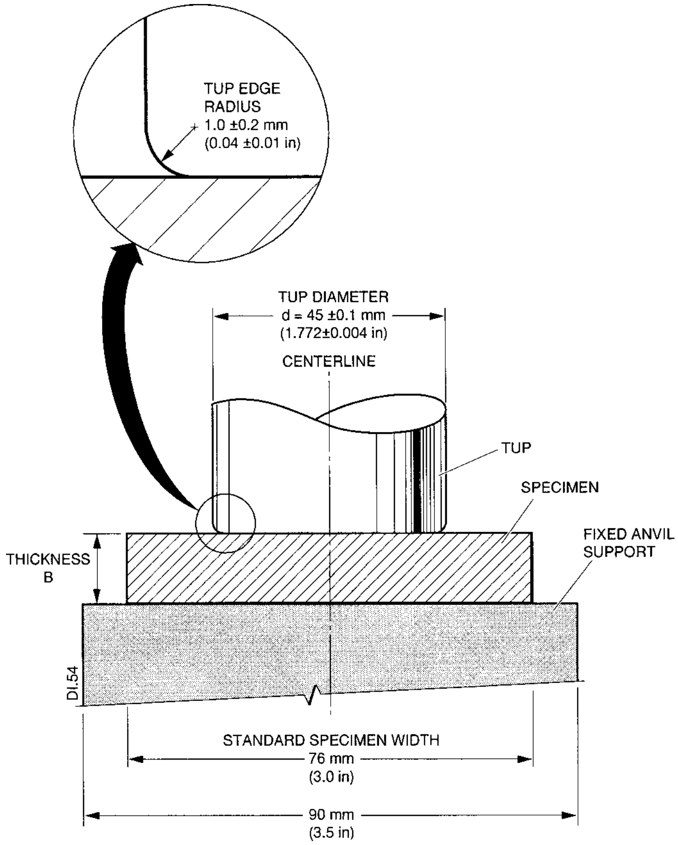


FIG. 2 Dimensional and Alignment Details

than that of the falling mass. The mass of the fixed anvil assembly shall be 170 kg (weight of 374 lb) or greater.

6.1.1.2 *Procedures B and C*—Rigid conditions for Procedures B and C can be obtained by limiting the displacement of the fixed anvil assembly to no more than 2 % of that applied to the specimen.

6.1.1.3 Specimens shall be secured to the fixed anvil support by any suitable technique that prevents transverse movement during the cyclic load conditioning (see Section 8) and does not prestrain the area of the specimen to be contacted by the tup more than 5 % (see 11.4).

NOTE 8—For Procedure A, elastic cords or duct tape have been successfully employed to secure the specimen to the fixed anvil support. For Procedures B and C see 9.3.2 and 9.3.3, respectively.

6.1.2 *Driven Plunger Assembly*, consisting of moveable mass with tup of flat circular diameter of 45± 0.1 mm (1.772 ± 0.004 in.) that is normal to the direction of force application, see Fig. 1 and Fig. 2. The edge of the tup shall be rounded, with a radius of 1.0 ± 0.25 mm (0.04 ± 0.01 in.) to prevent adverse specimen tearing at the edge. The tup area shall be centered on the fixed anvil assembly with the direction of force application being coincident ±2.5 mm (0.1 in.) with a line which passes through the center of mass of both the fixed anvil support and driven plunger assemblies, see Fig. 2.

6.1.2.1 The testing machine shall be capable of cycling (that is, loading and unloading as one cycle) the compression displacement of the specimen, see 8.2.2.

6.1.3 *Procedure A*—The standard method requirement for a maximum energy applied of 5 ± 0.5 J (44.2 ± 4.4 in.-lb) is achieved by use of specific impact mass and drop height. Acceptable values for these machine variables are 8.5 ± 0.1 kg for mass (a weight of 18.7 ± 0.2 lb) and 50 ± 2.5 mm (1.97 ± 0.098 in.) for initial (first impact cycle) drop height, see Fig. 1(*a*). The mass of the tup is included in the total impact mass and shall be less than 0.2 kg (0.4 lb). This can be accomplished by use of aluminum alloy 6061.

NOTE 9—The maximum energy applied is dependent on specimen displacement, see Note 7. The displacement will vary with the specimen thickness and for most material systems of interest for athletic footwear, the maximum displacement for this test method will be in the range from 5 to 15 mm (0.2 to 0.6 in.).

6.1.3.1 The velocity of the driven plunger assembly at the start of specimen compression shall be measured by any suitable means which has an accuracy of at least ±2 %, see 6.3.

6.1.3.2 Adverse loss of energy by the falling mass shall be avoided by having the measured impact velocity for the first impact cycle be within ±2 % of that for a free-falling object, that is given by $(2\ g\ h)^{0.5}$, where g is the gravitational constant and h is the drop height.

6.1.3.3 The velocity at the beginning of impact loading (for the 26th impact cycle) depends on the unrecovered specimen thickness. Velocity for the first impact cycle shall be in the range from 0.94 to 1.02 m/s (3.08 to 3.35 ft/s).

6.1.3.4 The testing machine shall be capable of initiating the impact cycle (that is, loading and unloading as one cycle) at a rate of one every 2 ± 1 s for the specimen conditioning (see section 8.2.2).

NOTE 10—For Procedure A the rates of loading and unloading are controlled by the initial impact velocity and the inherent shock attenuating properties of the specimen. Typical times to peak force will be in the range from 10 to 20 ms.

6.1.3.5 *Procedure B*—For Procedure B the rate of loading and unloading is controlled by the machine, see Fig. 1(*b*). The peak force selected for machine control shall be reached in a loading time of 15 ± 5 ms. The force-time curve shape, for the complete load/unloading cycle, can approximate that for a half sine function, see Fig. 3(*a*) and Note 11. Specimen conditioning (see section 8.2.2) requires a pause of 2 ± 1 s between load cycles, see Fig. 3(*b*).

NOTE 11—There are a variety of acceptable techniques for approximating the half sine function. The haversine is an example of an acceptable function for this test method.

6.1.3.6 *Procedure C*—For Procedure C the rate of loading and unloading is controlled by the machine. The peak displacement selected for machine control shall be reached in a loading time of 15 ± 5 ms. The displacement-time curve shape, for the complete loading/unloading cycle, can approximate that for a half sine, see Fig. 3(*a*) and Note 11. Specimen conditioning (see section 8.2.2) requires a pause of 2 ± 1 s between load cycles, see Fig. 3(*b*).

6.2 The instrumentation for data acquisition and display shall consist of systems for determination of force and displacement during the complete impact cycle (loading and unloading), as well as, the system for generation of the force-displacement relationships, see Appendix X2.

6.2.1 *Force Sensing System*—A force transducer, of sufficiently high natural frequency, used together with a calibrating

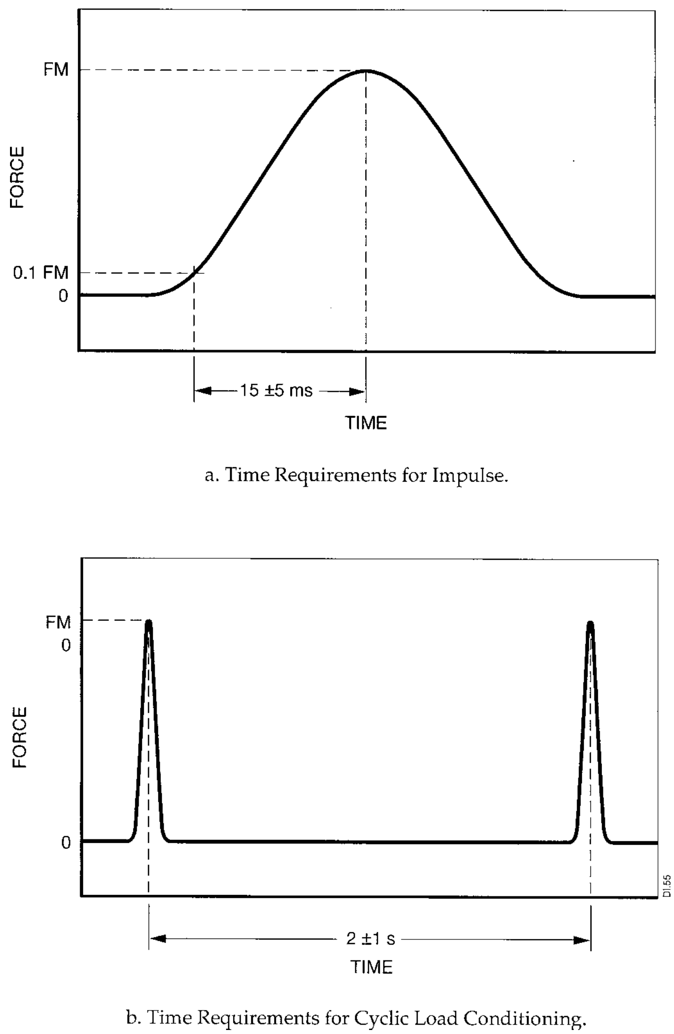


FIG. 3 Rapid Rate Force-Time Details for Procedures B and C

network for adjusting force sensitivity. This transducer shall be securely fastened so that force can be measured within ±2.5 mm (0.1 in.) of the central axis of the driven plunger assembly.

6.2.1.1 A variety of dynamic force transducers are commercially available and include: strain gage devices, piezo-electric transducers, and accelerometers. For Procedure A, the mass of the tup assembly between force transducer sensing area and specimen can influence the force or acceleration data, see X2.1.5. The calibration factor employed for converting transducer voltage values to force or acceleration units can be adjusted to account for the effects of the tup assembly mass, see M_r in X2.1.5.

6.2.1.2 The force transducer shall be capable of measuring compressive forces of up to 3.5 kN (781 lb). Peak force is dependent on specimen thickness and material properties. Values will be less than 2 kN (450 lb) for impact loading of a typical midsole material by this test method.

6.2.1.3 The minimum acceptable natural frequency for this test method is 500 Hz. The mass of the tup (see 6.1.2) attached to the force transducer will reduce the resonant frequency. Therefore, this natural frequency requirement applies to the assembly of tup and force transducer. This requirement does not apply for use of a force platform in the fixed anvil assembly. The requirement for natural frequency applies to all links of the instrument train from force transducer through to signal recording and display instrumentation. This is an "end-to-end" system requirement.

6.2.1.4 The minimum acceptable sampling rate for force or acceleration measurements is 1000 Hz (that is, measurement resolution of 1.0 ms).

6.2.1.5 The force transducer shall be employed in a manner which results in determination of any peak force to within ±3 % of value, see 6.3.

6.2.2 *Displacement Sensing System*—A means of monitoring the displacement of the moving assembly during the loading and unloading of the complete impact event. This can be accomplished through the use of a transducer or potentiometer attached directly to the system. Photographic or optical systems can also be utilized for measuring displacement. Typical displacement values will be in the range from 5 to 15 mm (0.2 to 0.6 in.) for specimen thicknesses of 5 to 35 mm (0.4 to 1.4 in.).

6.2.2.1 The minimum acceptable natural frequency for this test method is 500 Hz. The requirement for natural frequency applies to all links of the instrument train from displacement transducer through to signal recording and display instrumentation.

6.2.2.2 The minimum acceptable sampling rate for displacement measurements is 1000 Hz (that is, measurement resolution of 1.0 ms).

6.2.2.3 The determination of displacement shall be such that the reported values are within ±3 % of actual value, see 6.3.

6.2.2.4 *Procedure A*—For this procedure, displacement may be calculated as a function of velocity, impact mass, and the force (or acceleration) versus time data, through use of a suitable microprocessor system. Typical analytical relationships for this calculation are given in Appendix X2.

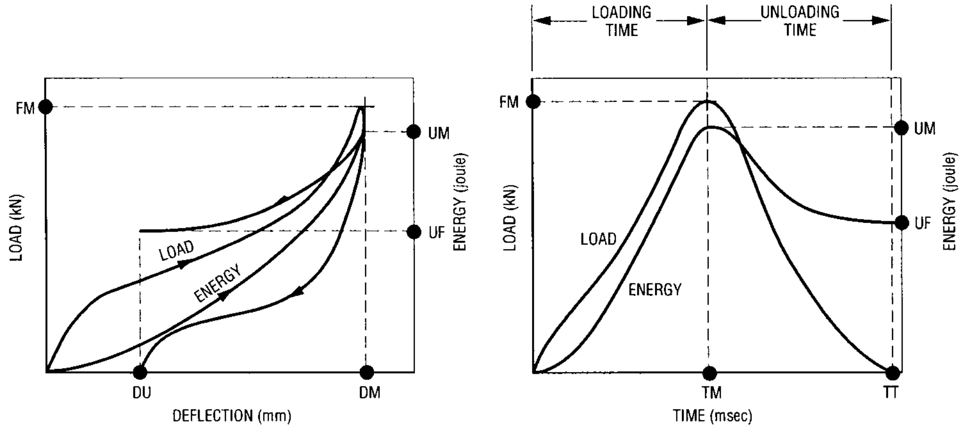
NOTE 12—When displacement is determined by a direct contacting (that is, attached to "fixed anvil assembly" and "driven plunger assembly") transducer, care must be taken to avoid adverse frictional energy loss, see 6.1.2.1.

6.2.2.5 *Procedures B and C*—For most machines displacement is measured directly from the driven assembly by a suitable transducer. The requirements of 6.2.2.1-6.2.2.3 are applicable to these procedures.

6.2.3 *Recording and Display Instrumentation*—Use any suitable means to record and display the data developed from the force and displacement sensing systems, provided the response characteristics are capable of presenting the data sensed with minimal distortion.

6.2.3.1 The requirements of 6.2.1.3-6.2.1.5 and 6.2.2.1-6.2.2.3 for force and displacement sensing systems, respectively, are applicable to the recording instrumentation.

6.2.3.2 The apparatus should display either force as a function of displacement, or force and displacement as a function of a common time scale. It is convenient to also display the calculated (see 11.5) specimen absorbed energy as a function of time or displacement. One of the preferred data displays is illustrated in Fig. 4.



DESCRIPTION	DATA PARAMETER TIME	LOAD	ENERGY	DEFLECTION
End of First Half of Compression Cycle	TM	FM	UM	DM
Completion of Compression Cycle	TT	—	UF	DU

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FIG. 4 Typical Data Displays for Shock Absorbing Tests

6.2.3.3 A variety of microprocessor-based systems for recording and generation of data displays are commercially available.

6.3 The complete mechanical and electronic apparatus shall be checked for calibration and performance to the requirements of 6.1 and 6.2 at least once every twelve months.

7. Specimens

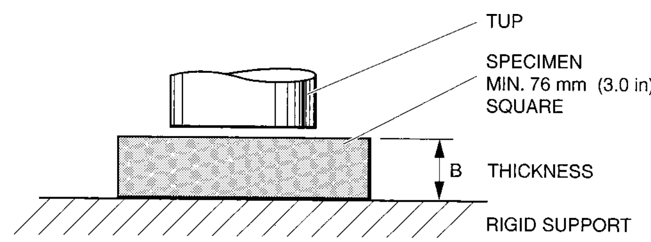
7.1 *Geometry*—The standard specimen geometry shall be as shown in Fig. 5(*a*). This is a block of thickness, *B*, with parallel faces for those in contact with the driven assembly tup and fixed anvil support. The minimum cross-sectional dimensions are 76 mm^2 (3 $in.^2$). The *B* dimension shall be in the range from 5 to 35 mm (0.2 to 1.4 in.) and is a critical value for identification/qualification of the resultant test data.

7.2 *Nonstandard Geometry*—This test method might be used to measure the shock-attenuating characteristics of specimens having irregular surface alignments at tup and support anvil surfaces, see Fig. 5(*b*). This could be the case for end-use product specimens of insole/midsole/outsole. The validity for comparisons of results from tests of specimens of nonstandard geometry has not been determined.

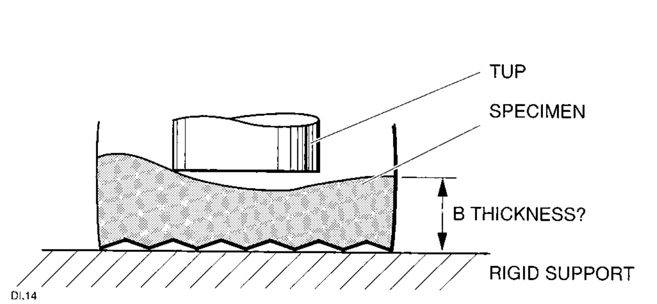
7.2.1 Reasonable comparative information may be obtained when the dimensional and geometrical parameters of specimens are held constant.

8. Conditioning

8.1 Condition the test specimens as required by the specifications for the material or as agreed upon by the interested parties.



a. Standard Specimen.



b. Non-Standard Specimen.

FIG. 5 Specimen for Shock Absorbing Tests

NOTE 13—Material systems for the midsole of athletic footwear are susceptible to changes in shock-attenuating properties as a result of exposure to: elevated temperature, high humidity, and time-dependent displacement history. For example, conditions which would simulate running on a hot summer day.

NOTE 14—Due to differing thermal conductivities and the time dependence of temperature profiles in most materials exposed to extreme surface temperature changes, there may be variability introduced by conditioning specimens at temperatures other than ambient.

NOTE 15—Foam materials for use in the midsole of athletic footwear tend to lose their shock-attenuating abilities from the first impact. This decay is generally logarithmic with respect to the impact cycles[2,8].

8.2 Do not stack the specimens during temperature and humidity conditioning.

8.3 The standard conditions for conditioning specimens for testing by this test method are:

8.3.1 Immediately prior to collection of shock-attenuating data by this test method, condition the specimens by repeated dynamic compression load cycling (one cycle is the complete loading and unloading) for a total of 25 cycles. Shock-attenuation data (see 9.5) is collected for the 26th through 30th cycles.

8.3.1.1 For Procedure A the impact rate is one cycle every 2 ± 1 s.

8.3.1.2 For Procedures B and C the cyclic loading is a series of compression cycles with each separated by a pause of 2 ± 1 s, see Fig. 3(*b*). Determine the rate for each compression cycle by the requirement of 6.1 for the time to peak force being 15 ± 5 ms, see Fig. 3(*a*).

8.3.1.3 The maximum applied energy (5 ± 0.5 J) requirement for Procedures B and C (see 9.4.2 and 9.4.3) may involve several trial load cycles. Reasonable care can limit these cycles to less than five. Use a pause of at least 1 min between the set-up load cycles and the 25 specimen conditioning cycles[8]. The set-up cycles are not part of the standard requirement for 25 conditioning cycles.

NOTE 16—Twenty-five cycles is a practical convenience for Procedure A and is not related to any known athletic footwear product performance factor. One thousand cycles is a frequently used conditioning for end-use products.

NOTE 17—The hysteresis energy loss during the compression cycle can result in an increase of temperature, which can reduce the stiffness of the specimen.[8] The pause after the set-up cycles is intended to provide for more uniform results from the 25 conditioning cycles.

8.3.2 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73.4 ± 3.6°F), unless otherwise specified. In cases of disagreements, the tolerances shall be ±1°C (1.8°F).

8.4 Store specimens to be tested at other than the standard conditioning for temperature and humidity in the desired environment for at least 4 h, or until they reach the desired temperature, before testing. Test specimens (that is, the first impact loading) within 10 s after removal from the environmental chamber. Testing at other than ambient precludes conducting the cyclic loading (see 8.3.1).

9. Procedure

9.1 Measure and record the thickness (*B*) of the specimen to the nearest 0.5 mm (0.02 in.) at the impact area.

9.2 Condition the specimen for temperature as specified in 8.3.

9.3 Secure the specimen on the fixed anvil assembly (see 6.1.1.3) so that it is centered beneath the tup of the driven assembly (see 6.1.2).

9.3.1 *Procedure A*—For Procedure A, hold the specimen in position so that excessive transverse motion does not occur during the impact conditioning (see section 8.2.1), see Note 8.

9.3.2 *Procedure B*—For Procedure B, secure the specimen in the desired position through use of a minor prelude. Values of 10 to 20 *N* (2.25 to 4.5 lb) are acceptable for the prelude securing of the specimen.

9.3.3 *Procedure C*—For Procedure C, secure the specimen in the desired position through use of a minor displacement preset. Values of 0.05 to 0.1 mm (0.002 to 0.004 in.) are acceptable.

9.4 Select and adjust machine for required test parameters of loading rate and maximum energy applied to the specimen. The machine requirements are stated in Section 6. The general intention of this test method is to load a specimen with a 5 ± 0.5-J maximum energy applied and an attendant time to peak force or displacement of 15 ± 5 ms.

9.4.1 *Procedure A*—Adjust drop height (h) to 50 ± 2.5 mm (1.97 ± 0.098 in.). The impact mass shall be 8.5 ± 0.1 kg, that is a weight of 83.27 ± 0.98 N (18.72 ± 0.22 lb).

9.4.2 *Procedure B*:

9.4.2.1 Select a loading rate that will result in peak force being reached in 15 ± 5 ms.

9.4.2.2 Run a few load cycles, using an iteration method, to adjust rate (see 9.4.2.1) and peak force (FM) until the maximum energy applied (that is, at FM) is within the required range from 4.5 to 5.5 J (39.8 to 48.6 in.-lb).

9.4.2.3 The iteration should require no more than five cycles that are not part of the specimen conditioning, see 8.3.1.2. If the load values or cycles are excessive (as evidenced by any permanent changes in specimen thickness), replace the specimen with a replicate.

9.4.3 *Procedure C*:

9.4.3.1 Select a loading rate that will result in peak displacement being reached in 15 ± 5 ms.

9.4.3.2 Run a few load cycles, using an iteration method, to adjust peak displacement (*DM*) until the maximum energy applied (that is, at *DM*) is within the required range from 4.5 to 5.5 J (39.8 to 48.6 in.-lb).

9.4.3.3 The iteration should require no more than five cycles that are not part of the specimen conditioning, see 8.3.1.2. If the displacement values or cycles are excessive (as evidenced by any permanent changes in specimen thickness), replace the specimen with a replicate.

9.5 Perform the impact conditioning of 8.3.1 and with no pause between, record the desired test data for the load-displacement records of the following five impact cycles. The cyclic loading requirements for the data collection cycles shall be that of 8.3.1.

9.6 Remove the specimen and note any unusual damage/degradation of surface appearance which may have occurred.

10. Calculation

10.1 Using the force versus displacement information and appropriate scaling factors, determine the following. These values are graphically illustrated in Fig. 4:

[8] Poliner, J., et al, "The Importance Of Thermo-Mechanical Properties In The Selection Of Athletic Shoe Cushioning Foams," paper presented at American Society of Biomechanics Annual Meeting, Fall 1991.

10.1.1 Peak force (*FM*), in newtons (or pounds-force),

10.1.2 Maximum displacement (*DM*), in millimetres (or inches),

10.1.3 Maximum energy applied (*UM*), in joules (or inch-pounds-force) to the point where peak displacement occurred,

10.1.4 Hysteresis energy (*UF*), in joules (or inch-pounds-force) to the point, after peak force, where force equals zero, and

10.1.5 Time (*TM*), in milliseconds to the point where peak displacement occurred.

10.2 *Normalization*—The values of peak force and displacement should be normalized to provide values better suited for comparative evaluations. The basis for this computation is a reference maximum energy applied of 5 J (44.2 in.-lb), see Notes 1-4. The normalization computation was derived from the elastic spring relationship for *F, D* and *U*.

$$X\,(\text{normalized}) = X(UR/UM)^{1/2} \tag{1}$$

where:
X = *FM* or *DM* value,
UR = reference energy of 5J (44.2 in.-lb), and
UM = measured maximum energy applied (see 10.1.3), that must be within ±10 % of UR (4.5 to 5.5 J).

NOTE 18—The normalization is intended to compensate for practical variations in experimental technique and the inherent displacement characteristics of different materials.

NOTE 19—Although the normalization is based on linear elastic mechanics relationships, the probable error for typical nonelastic midsole materials is less than ±3 %, when *UM* is in the required range.

10.3 *Calculations*—Using the above values of normalized *FM* and *DM, UM,* and *UF*, and the independent test variables of specimen thickness (*B*) and tup diameter (*d*) calculate the following:

10.3.1 Normalized peak pressure (*PM*, see 11.2), in units of megapascals (kilonewtons per square metre) (or pounds-force per square inch) to two significant figures,

10.3.2 Normalized peak strain (*eM*, see 11.4), to two significant figures,

10.3.3 HER (hysteresis energy ratio, see 11.6) to two significant figures, and

10.3.4 Normalized average stiffness (*Sm*, see 11.7), in units of newtons per millimetre (or pounds-force per inch) to two significant figures.

10.4 For the series of five impact cycles (that is, Cycles 26 through 30), calculate the arithmetic mean (*Xm*) and the estimated standard deviations (*S*) for each of the above to two significant figures:

$$S = \frac{(\Sigma X^2 - nXm^2)^{1/2}}{n - 1} \tag{2}$$

where:
X = value of a single observation, and
n = number of observations.

11. Interpretation of Results

11.1 *Force*—The force (*F*) values required for this test method are those applied to the specimen through the 45- mm (1.8-in.) diameter (*d*) flat tup.

11.1.1 Most instrumentation employed for this test method will present the desired force values as a function of either time or displacement, see Fig. 4.

11.1.2 Instrumentation that uses an accelerometer for determination of force will require use of the weight (*w*) value of the impact mass to calculate force (*F*) from the measured *G* values. The required relationship is $F = wa/g$.

NOTE 20—*G* is a dimensions value determined as the ratio of actual acceleration (*a*) to gravitational acceleration constant (*g*). That is, *G* is the number of *g*'s of acceleration ($F = ma = wa/g$, where $m = w/g$).

11.2 *Pressure*—It is convenient to use the pressure (*P*) applied by the tup surface to express shock absorbing responses. This value is defined as the ratio of force (*F*) to the cross-sectional area of the tup and can be computed from:

$$P = 4F/(\pi d^2) \tag{3}$$

With the tup diameter (*d*) in units of millimetres and *F* in units of Neutons, the pressure (*P*) will have units of Megapascals.

11.3 *Displacement*—The displacement (*D*) values required for this test method are those of the top surface of specimen at the contact area with the tup of the driven assembly. The *D* values are obtained by either measurement or computation of the motion of the driven assembly.

11.3.1 *Procedure A*—For Procedure A, calculate displacement by one of two methods that depend on whether a force transducer or an accelerometer is used. The calculations are conveniently performed through use of microprocessor or laboratory computer devices, see Appendix X2.

11.3.2 *Procedures B and C*—Most machines employed for Procedures B and C of this test method utilize direct measurement of the displacement by monitoring the driven assembly motion. Secondary calculations are not necessary.

NOTE 21—There is no evidence to support a preference for calculated or measured values of displacement for this type of test (see Test Method D 3763).

11.4 *Strain*—Although not required for this test method, some studies may use the strain (ϵ) in the direction of force application by the tup to express shock attenuating responses. This value is defined as the ratio of displacement (*D*) to specimen thickness (*B*) and can be computed from:

$$\epsilon = D/B \tag{4}$$

11.5 *Energy*—The energy values required for this test method are those of the energy absorbed by the specimen as a result of the applied load-displacement. Energy can be determined by direct integration of the load-displacement record.

11.5.1 *Procedure A*—Energy at any time during impact can be computed from the relationships shown in Appendix X2. Most instrumentation employed for this test method will present the desired energy values as a function of either time or displacement, see Fig. 4.

11.6 *Hysteresis Energy Ratio*—This is defined (see 3.1.12) as HER and is the ratio of the hysteresis energy (*UF*) to the maximum energy applied (*UM*). The energy values are graphically identified in Fig. 4:

$$HER = UF/UM \quad (5)$$

NOTE 22—The *HER* should be considered to be dependent upon: rate of force application and removal, thickness of specimen (*B*), and peak strain (*DM/B*). For this test method *HER* is a good comparative parameter.

NOTE 23—The *HER* will vary from 0 to 1 depending on the shock attenuating properties of the specimen. That is, no energy returned to the driven assembly will have *HER* = 1.

11.7 *Average Stiffness*—This is defined as the ratio of peak force to maximum displacement and can be computed from:

$$Sm = FM/DM \quad (6)$$

NOTE 24—The force-displacement curve for the loading portion of the compression cycle is not linear and can be examined in terms of two or more displacement stages, for which each have a distinct slope or stiffness. The Sm is intended for use as a first-order estimate.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, and previous history,

12.1.2 Specimen size and thickness,

12.1.3 Source and types of test equipment,

12.1.4 Procedure identification (A, B, or C),

12.1.5 For the series of five impact cycles, average value and standard deviation for each of the properties listed in 10.1, 10.2, and 10.3,

12.1.6 Reference maximum energy applied (UR), 5 J is standard for this test method, and

12.1.7 Comments regarding visual appearance of specimen degradation (see 9.6).

13. Precision and Bias

13.1 *Precision*—An interlaboratory study was conducted during the development of this test method. Six laboratories ran a series of five tests on each of three cushioning materials using Procedure A with a reference maximum energy of 5.0 J. Normalized peak force (FM) and hysteresis energy ratio (HER) were determined. From the results of these tests, precision statistics were calculated in accordance with Practice E 691.

13.1.1 The precision results summarized in Table 1 and Table 2 and for the comparison of six test results, each of which is the average of five test determinations.

13.2 *Bias*—A statement on bias cannot be made because no reference samples are available.

TABLE 1 Precision Statistics for Normalized Peak Force

NOTE 1—All values expressed in newtons, except 95 % repeatability and reproducibility limits, which are expressed as percents of the mean test value.

	Material A	Material C	Material B
Mean test value	643.5	1048.1	2146.4
Cell deviation	34.7	41.3	277.6
Repeatability standard deviation (within laboratories)	5.4	4.8	21.0
Reproducibility standard deviation (between laboratories)	35.0	41.5	278.3
95 % repeatability limit (within laboratories)	2.3 %	1.3 %	13.0 %
95 % reproducibility limit (between laboratories)	15.2 %	11.1 %	18.2 %

TABLE 2 Precision Statistics for Hysteresis Energy Ratio

NOTE 1—All values are unitless as they are ratios. The 95 % repeatability and reproducibility limits are expressed as percentages of the mean test value.

	Material A	Material C	Material B
Mean test value	0.411	0.592	0.649
Cell deviation	0.028	0.077	0.046
Repeatability standard deviation (within laboratories)	0.003	0.005	0.004
Reproducibility standard deviation (between laboratories)	0.029	0.078	0.046
95 % repeatability limit (within laboratories)	2.2 %	2.4 %	1.5 %
95 % reproducibility limit (between laboratories)	21.7 %	36.7 %	20.0 %

APPENDIXES

(Nonmandatory Information)

X1. SPECIMEN CONDITIONING

X1.1 This test method requires the specimen to be preconditioned by cyclic impact loading before evaluation of the shock absorption and resilience characteristics. The requirement of 8.3.1 is for 25 impact cycles with data collected on the immediate following five cycles.

X1.2 Foam materials for use in the midsole of athletic footwear tend to lose their shock-absorbing abilities from the first impact. The rate of change is generally logarithmic after the first 25 cycles.[9] The slope of this logarithmic function would be characteristic of the specific material.

X1.3 The selection of 25 impact cycles for the specimen conditioning of this test method was strongly influenced by considerations for the practical operation of drop weight devices for Procedure A. The inherent automation of machine operation for those employed for Procedures B and C would permit a practical increase in the conditioning impact cycles to approximately 1000. Subsequent modifications of this test method may result in this type of change for Procedures B and C. At this time the test method development requires comparative data between the three Procedures of A, B, and C.

[9] See Footnote 2.

X2. PROCEDURE A COMPUTATIONS

X2.1 Procedure A of this test method provides for calculation of specimen absorbed energy (*U*) and displacement (*D*). There are several different but equivalent techniques for these calculations. This addendum presents one of the commonly used techniques for instrumented impact test force transducer and accelerometer data. If alternate analytical relationships are used for this test method, the user is cautioned to comply with the following:

X2.1.1 The absorbed energy (*U*) of the specimen is equal to the **TOTAL** potential energy change of the impacting mass.

$$U = w(h_o + D) \tag{X2.1}$$

where:

w = weight of the impacting mass,
h_o = distance traveled by the impacting mass to the start of the specimen compression, and
D = specimen displacement during the compression.

NOTE X2.1—If a pendulum was used and impact occurred at the bottom of the arc, the total potential energy change is the product $w\, h_o$.

X2.1.2 Displacement (*D*) is not the product of space average velocity and time.

X2.1.3 Mass (*m*) and weight have different units and are related by $m = w/g$. The 8.5-kg mass has a weight of 83.27 N (18.72 lb) at the nominal gravitational acceleration rate of 9.81 m/s^2(32.17 ft/s^2).

X2.1.4 Accelerometers provide acceleration changes (*G*) that are referenced to the gravitational constant (*g*). Force (*F*) is related to *G* by $F = w\,G$.

X2.1.5 The mass of the tup assembly (weight = w_t) between force transducer and specimen is part of the total impact mass and can influence the force or acceleration data. The values provided by the transducer will be lower than the actual interaction value between tup and specimen. The measured values should be multiplied by the ratio M_r, where $M_r = w/(w - w_r)$. The tup assembly mass requirements of 6.1.2.1 limit this correction to less than approximately 2 %. The apparatus requirements of 6.2.1.5 provide for a ±3 % of value tolerance on the measured force values.

X2.1.6 The velocity of the impacting mass is changing as the result of two simultaneous actions; (*1*) gravity and (*2*) impulse. These are identified in the subsequent discussion of this appendix.

X2.2 The following discussion is based on the consideration that; (*1*) the weight (*w*) of the impacting mass is known, (*2*) the velocity (v_o) of the impacting mass at the start of compression of the specimen has been measured (see 6.1.3.1), (*3*) either a force transducer or an accelerometer has been used to collect a digital array of (F_i, t_i) or (G_i, t_i), and (*4*) a computer is available to process the data.

X2.3 The digital data must comply with the requirements of 6.1 and 6.2. The maximum allowable time interval ($t_i - t_{i-1}$) for sampling individual values of force (F_i) or acceleration (G_i) data is 1.0 ms. A minimum of 20 F_i or G_i specimens are required for the complete compression cycle of loading and unloading. The minimum acceptable natural frequency is 500 Hz for the data collection instrumentation and the assembly of tup and force transducer (see 6.2.1.3).

X2.4 *Force Time Data:*

X2.4.1 The input information for the computations consist of the weight (*w*) of the impacting mass, the weight (w_t) of the tup assembly (that is part of the impacting mass), the array of force-time (F_i, t_i) data from the force transducer, and the measured velocity (v_o) of the impacting mass at the start of compression displacement. The force data should be corrected by the relationship identified in X2.1.5, depending on the mass of the tup assembly between the transducer and the specimen. The velocity (*v*) of the impacting mass, specimen displacement (*D*), and specimen absorbed energy (*U*) can be determined from the following relationships:

$$v_i = v_{i-1} + g(t_i - t_{i-1}) - (F_i/m)(t_i - t_{i-1}) \tag{X2.2}$$

$$D_i = D_{i-1} - (v_i^2 - v_{i-1}^2)/(2(F_i/m - g)) \tag{X2.3}$$

$$U_i = U_{i-1} + F_i(D_i - D_{i-1}) \tag{X2.4}$$

Each equation is arranged to indicate the value for the current time increment (t_i) is equal to that for the previous increment (t_{i-1}) plus or minus the change that occurred between increments.

X2.4.1.1 The changes in velocity (see Eq X2.2) come from two sources, gravity and impulse. The velocity (v_i) for the first increment ($i = 1$) equals $v_o$that is the measured value at the start of the compression. As the impacting mass continues to move downward during specimen compression, there is a gravitational contribution to velocity. This is the product $g(t_i - t_{i-1})$ shown in Eq X2.2.

X2.4.1.2 Impulse is the product of force and time and is equal to momentum change which is the product of mass and the velocity change. The statement of impulse being equal to momentum change can be represented as follows:

$$F_i(t_i - t_{i-1}) = m(v_i - v_{i-1}) \tag{X2.5}$$

Eq X2.5 is rearranged to find the impulse contribution to the velocity change shown in Eq X2.2.

X2.4.1.3 The displacement change (see Eq X2.3) over the time change from t_i to t_{i-1} is derived from equating the energy change of the specimen to the work done on the specimen by the impact force. The energy (*U*) done on the specimen is the negative of the energy change of the impacting mass and can be represented as the sum of kinetic energy (*UK*) and potential energy (*UP*) contributions.

$$UK_i - UK_{i-1} = -m(v_i^2 - v_{i-1}^2)/2 \tag{X2.6}$$

$$UP_i - UP_{i-1} = \text{mg}\,(D_i - D_{i-1}) \tag{X2.7}$$

$$U_i - U_{i-1} = (UK_i - UK_{i-1}) + (UP_i - UP_{i-1}) \tag{X2.8}$$

The work done on the specimen can also be expressed as the integral of force with respect to displacement, as shown in Eq X2.4. Eq X2.6, Eq X2.7, Eq X2.8, and Eq X2.4 can be combined and rearranged to yield the displacement change relationship shown in Eq X2.3.

X2.4.1.4 The change in specimen absorbed energy (see Eq X2.4) between time increments is based on integrating the force displacement data.

X2.5 *Acceleration Time Data:*

X2.5.1 The input information for the computations consist of the total weight (w) of the impacting mass, the weight (w_t) of the tup assembly (that is part of the impacting mass), the array of acceleration-time (G_i, t_i) data from the accelerometer, and the measured velocity (v_o) of the impacting mass at the start of compression. The force data should be corrected by the relationship identified in X2.1.5, depending on the mass of the tup assembly between the transducer and the specimen.

X2.5.1.1 The velocity (v) of the impacting mass, specimen displacement (D), and specimen absorbed energy (U) can be determined from the following relationships. These equations differ from those used for the force (F) transducer data (X2.4) by the relationship of $F = w G$.

$$v_i = v_{i-1} + g(t_i - t_{i-1}) - gG_i(t_i - t_{i-1}) \quad \text{(X2.9)}$$

$$D_i = D_{i-1} - (v_i^2 - v_{i-1}^2)/(2g(G_i - 1)) \quad \text{(X2.10)}$$

$$U_i = U_{i-1} + wG_i(D_i - D_{i-1}) \quad \text{(X2.11)}$$

Each equation is arranged to indicate the value for the current time increment (t_i) is equal to that for the previous increment (t_{i-1}) plus or minus the change that occurred between increments.

X2.5.1.2 The changes in velocity (see Eq X2.9) come from two sources, gravity and impulse. The velocity (v_i) for the first increment ($i = 1$) equals v_o that is the measured value at the start of the compression. As the impacting mass continues to move downward during specimen compression, there is a gravitational contribution to increase velocity. This is the product g ($t_i - t_{i-1}$) shown in Eq X2.9.

X2.5.1.3 Impulse is the product of force and time, and is equal to momentum change which is the product of mass and the velocity change. Force (F_i) is determined as the product of weight (w) and acceleration change (G_i), $F_i = wG_i$. The statement of impulse being equal to momentum change can be represented as follows:

$$wG_i(t_i - t_{i-1}) = m(v_i - v_{i-1}) \quad \text{(X2.12)}$$

Eq X2.12 is rearranged, with the substitution of w/g for m, to find the impulse contribution to the velocity change shown in Eq X2.9.

X2.5.1.4 The displacement change (Eq X2.10) for the time change from t_i to t_{i-1} is derived from equating the energy change of the specimen to the work done on the specimen by the impact force. The energy (U) done on the specimen is the negative of the energy change of the impacting mass and can be represented as the sum of kinetic energy (UK) and potential energy (UP) contributions:

$$UK_i - UK_{i-1} = -m(v_i^2 - v_{i-1}^2)/2 \quad \text{(X2.13)}$$

$$UP_i - UP_{i-1} = \text{mg}\,(D_i - D_{i-1}) \quad \text{(X2.14)}$$

$$U_i - U_{i-1} = (UK_i - UK_{i-1}) + (UP_i - UP_{i-1}) \quad \text{(X2.15)}$$

The work done on the specimen can also be expressed as the integral of force with respect to displacement, as shown in Eq X2.11, where $F_i = w\,G_{i-1}$. Eq X2.6, Eq X2.7, Eq X2.8, and Eq X2.11 can be combined and rearranged to yield the displacement change relationship shown in Eq X2.10.

X2.5.1.5 The change in specimen absorbed energy (see Eq X2.11) between time increments is based on integrating the force displacement data, where $F_i = w\,G_i$.