Designation: F3555 – 22

Standard Test Method for Measuring Impact Attenuation Characteristics of Helmets Under Induced Rotational Loading Using an Inclined Anvil[1]

This standard is issued under the fixed designation F3555; 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.

INTRODUCTION

This test method specifies equipment and procedures used for the evaluation of the impact attenuation characteristics of helmets under induced rotational loading using an incline anvil. It is the responsibility of each ASTM Committee to decide whether this test method is suitable for inclusion in their particular head protection standard. Individual ASTM performance standards (standard specifications) may use these procedures and equipment and may specify test conditions, pass-fail criteria, and other applicable performance requirements tailored to the needs of a particular activity (for example, hockey, football, baseball, etc.). This test method was developed using resources in medical, scientific, mechanical engineering, human factors, and biomechanical fields. However, it is recognized that it is not possible to write a performance standard that will include all possible impact scenarios. It is also recognized that serious injury or death can result from both low and high-energy impacts, even when a helmet is worn. This test method incorporates aspects of other recognized protective equipment performance standards. It draws from work done by others where appropriate for this test method. These standards are referenced within this standard test method. It should be noted that this test method specifies laboratory tests of helmets to measure its ability to reduce impact forces applied to the head and other selected parameters during normal use for the given activity.

1. Scope

1.1 This test method covers laboratory equipment, procedures, and basic requirements pertinent to testing the performance of helmets during rotational loading using an incline anvil. Deviations and additions to this test method will be specified, as required, in individual ASTM performance standards.

1.2 *Requirements*—The helmet may be tested under one or more specified environmental conditions for impact attenuation (the limiting of impact forces) as a result of a vertical free-fall onto an incline anvil.

1.3 Except where noted, the values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *SAE Standards:*[2]

SAE J211-1 Instrumentation for Impact Test – Part 1 – Electronic Instrumentation

SAE J1727 Calculation Guidelines for Impact Testing

2.2 *ISO Standard:*[3]

ISO 6344-2 Coated Abrasives – Determination and designation of grain size distribution – Part 2: Macrogrit sizes P12 to P220

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee F08 on Sports Equipment, Playing Surfaces, and Facilities and is the direct responsibility of Subcommittee F08.53 on Headgear and Helmets.

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[2] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.1 *alpha (α), n*—abbreviation for angular acceleration, expressed in units of radians per second-squared.

3.1.2 *area of coverage, n*—a specified area of the protective device that is intended to provide protection and is subject to specific testing.

3.1.3 *coronal plane, n*—an anatomical plane perpendicular to both the basic and midsagittal planes and containing the midpoint of a line connecting the left and right auditory meatuses.

3.1.4 *Frankfort plane, n*—a plane connecting the highest point of the opening of the external auditory canal with the lowest point on the lower margin of the orbit.

3.1.5 *helmet carrier, n*—a device designed to carry the test headform and test helmet along the guided rail system toward the incline anvil and to release the test headform and test helmet immediately prior to impact with the incline anvil.

3.1.6 *helmet position index (HPI), n*—the vertical distance from the brow of the helmet to the headform reference plane when the helmet is placed on the reference headform.

3.1.7 *midsagittal plane, n*—an anatomical plane perpendicular to the basic plane and containing the midpoint of the line connecting the notches of the right and left inferior orbital ridges and the midpoint of the line connecting the superior rims of the right and left auditory meatuses.

3.1.8 *nine accelerometer package (NAP), n*—a practical method for calculating rotational acceleration inside a manikin headform, including geometric corrections due to accelerometer placements, as described by diMasi (1995).[4]

3.1.9 *omega (ω), n*—abbreviation for angular velocity, expressed in units of radians per second.

3.1.10 *tragion, n*—the superior point on the juncture of the cartilaginous flap (tragus) of the ear with the head.

4. Significance and Use

4.1 The purpose of these test methods is to provide reliable and repeatable tests for the evaluation of various types of protective headgear when subjected to rotational loading. Use of these test methods in conjunction with the specific individual performance standards is intended to reduce the likelihood of serious injury and death resulting from impacts to the head sustained by individuals participating in sports, recreation, and other leisure activities in which protective headgear is worn.

5. Certification

5.1 Unless otherwise specified in the individual performance standard, these test methods permit self-certification. It is recommended that each manufacturer employ an independent test laboratory at least annually to test each model and size of head protection product offered for sale.

6. Test Methodology

6.1 *Test Apparatus*—The test apparatus shall consist of the following components and characteristics.

6.1.1 *Impact Base*—The impact base (see Fig. 1 Part C) shall be solid and made of steel or a combination of steel and concrete. The base shall have a mass of at least 500 kg. At least the uppermost 25 mm shall consist of steel, which shall be firmly attached to the concrete if present.

6.1.2 *Test Anvil*—Unless otherwise specified in the individual performance standard, the test anvil shall consist of a solid steel cylinder with a minimum diameter of 130 mm. The cylinder shall include a minimum 130 mm diameter impact face that has a 45 ± 0.5° angle from the horizontal plane (see Fig. 1 Part A). The minimum height of the steel region beneath the impact face shall be 30 mm (see Fig. 1 Dimension h). The minimum height between the impact base and the test anvil shall be 200 mm (see Fig. 1 Part B) and the length/diameter ratio of Part B shall not be greater than five. Unless otherwise specified in the individual performance standard, the impact face of the test anvil shall be covered with an abrasive paper, with a grain size distribution of P80 according to ISO 6344-2. The abrasive paper shall be securely attached to the anvil to avoid slippage. Unless otherwise specified in the individual performance standard, the abrasive paper shall be replaced after three single tests or if significant damage occurs.

6.1.3 *Guidance System and Helmet Carrier*—The guidance system shall provide for the positioning of any initial headform angle and impact point on the helmet vertically above the anvil. Details regarding the position and orientation of the headform and helmet shall be provided in the individual performance standard. The guidance system shall be attached to the helmet carrier in a manner that keeps the helmet in the target impact position during the raising, release and dropping of the headform/helmet assembly. The helmet carrier shall be designed in a manner that it does not influence the response of the headform/helmet assembly during the impact with the test anvil.

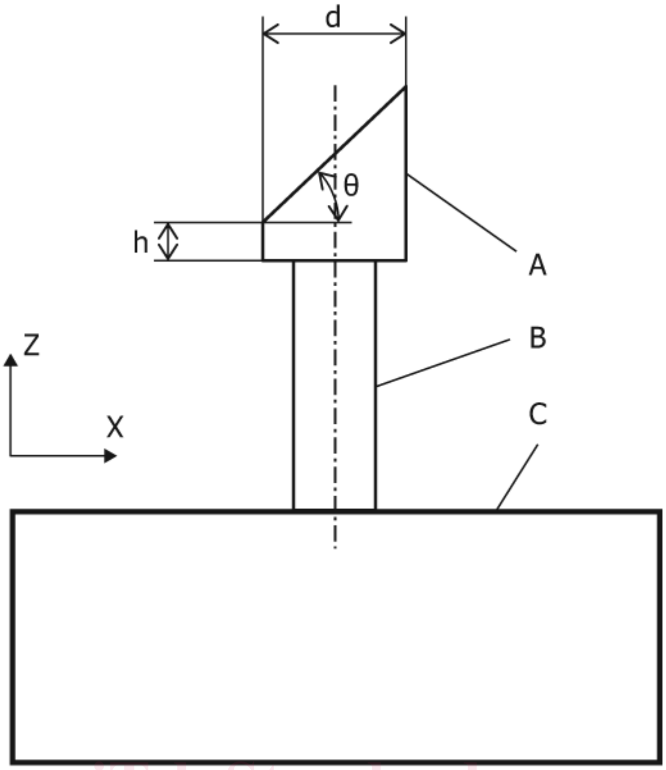
6.1.4 *Impact Velocity*—The headform/helmet assembly vertical impact velocity shall be measured at a distance not more than 40 mm prior to the impact. The target impact velocity and allowable tolerance shall be specified in the designated standard.

6.1.5 *Test Headforms*—The test headforms used with this specification shall be full size headforms that are listed in Table 1 and meet the dimensional specifications of Annex 6 of the UN/ECE 22.06 standard.[5,6] The external surface of each test headform shall have a coefficient of friction of 0.27 to 0.33

[4] DiMasi, F.P., Transformation of Nine-Accelerometer-Package (NAP) Data for Replicating Headpart Kinematics and Dynamic Loading: Technical Report DOT HS-808 282. Washington, DC, United States Department of Transportation, National Highway Traffic Safety Administration, 1995.

[5] United Nations, Economic commission for Europe, working party WP29 on the Construction of Vehicles, Regulation No. 22, Uniform provisions concerning the approval of protective helmets for drivers and passengers of motorcycles and mopeds, Geneva, Initially passed 1958, amendment 03 1988, amendment 04 1995, amendment 05 1999, amendment 06 2020.

[6] The sole source of supply of the test headforms known to the committee at this time is Cellbond, a division of Encocam Limited, 5 Stukeley Business Centre, Blackstone Road, Huntingdon, Cambridgeshire, PE29 6EF, United Kingdom (sales@cellbond.com). If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.



Where:
d = minimum of 130 mm
h = minimum of 30 mm
θ = 45 ± 0.5°

FIG. 1 Typical Inclined Anvil Impact Base and Test Anvil

TABLE 1 Inclined Anvil Impact Test Headform Properties (Right Hand Coordinate System)

Size Designation (Circumference in mm)	Mass including instrumentation (kg)^{A}	Center of Gravity (CG)			Moment of Inertia (MOI)		
		cg_x^{B} (mm)	cg_y^{B} (mm)	cg_z^{B} (mm)	I_{xx} (kg cm^2)^{C}	I_{yy} (kg cm^2)^{C}	I_{zz} (kg cm^2)^{C}
495	2.47	4.0	0.0	28.8	61.88	8.81	70.22
535	3.35	6.5	0.0	27.9	130.68	148.36	110.80
575	4.23	9.0	0.0	26.9	199.47	214.92	151.37
595	4.67	10.3	0.0	26.4	233.87	248.20	171.65
615	5.11	11.6	0.0	26.0	268.26	281.48	191.94
635	5.55	12.8	0.0	25.5	302.66	314.75	212.22

[A] Tolerance ± 2%.
[B] Tolerance ± 2 mm. Center of gravity locations are expressed relative to the tragion which is located on the Frankfort plane.
[C] Tolerance ± 5%.

which is equal to an average force gauge measurement of not less than 30 N and not more than 33 N when tested according to the procedures listed in 6.1.5.1. All headforms available for testing shall have the inertial properties specified in Table 1.

6.1.5.1 *Headform Surface Coefficient of Friction Test Procedure:*

(1) The test headform shall be positioned so that the reference plane is horizontal. The head form Z-axis shall point in the positive vertical axis. A 25 mm ± 0.5 mm wide polyester strap shall be placed on the test headform as shown in Fig. 2. The polyester strap shall have a minimum elastic modulus of 4 N/mm.

(2) The polyester strap shall be positioned over the test headform along the midsagittal plane of the headform such that at one end of the strap a mass of 2 kg ± 25 g shall be attached, and at the other end a force gauge shall be attached (see Fig. 2). Once the mass and the force gauge have been attached, pull the strap a distance of not less than 40 mm with a constant speed of 150 mm/min ± 15 mm/min and record the peak force required to move the strap on the headform. A series of three warm-up pulling cycles shall be executed to ensure the strap is properly positioned on the test headform. The peak force readings from the three warm-up pulling cycles shall be discarded. A total of five pulling cycles shall then be performed

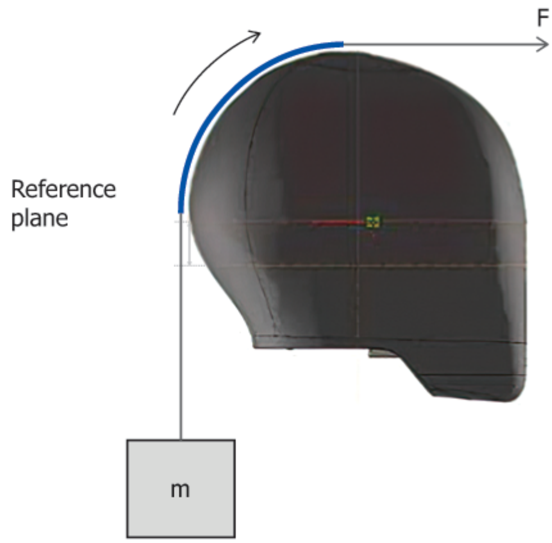


FIG. 2 Headform Surface Coefficient of Friction Test Setup

and the average force reported from the five pulling cycles shall be calculated and reported for each test headform. The entire test sequence shall then be repeated with the polyester strap oriented along the coronal plane of the reference headform.

7. Instrumentation, Data Acquisition and Signal Processing

7.1 *Headform Instrumentation*—The test headform shall be instrumented to measure both linear and rotational head kinematics in three dimensions about the headform's center of gravity. Any headform instrumentation system that is capable of meeting the inertial characteristics of Table 1 once installed into the test headform shall be acceptable. Two example systems are as follows:

7.1.1 *Nine Accelerometer Package (NAP)*—Nine uni-axial accelerometers are positioned in the 3-2-2-2 arrangement described by Padgoankar (1975)[7] and diMasi (1995).[4] The accelerometers shall be capable of withstanding a shock of at least 9810 m/s^2 (1000 g).

7.1.2 *Triaxial Linear Accelerometer and Angular Rate Sensor (ARS) System*—Three linear accelerometers are located at the center of gravity of the head along with three angular rate sensors (ARS). The linear accelerometers shall be capable of withstanding a shock of at least 9810 m/s^2 (1000g). The ARS shall have a measurement capacity of at least 150 rad/s and be capable of withstanding a direct shock of at least 1000 g and a maximum rotational velocity input of at least 314 rad/s.

7.2 *Calibration*—Transducers used under this standard shall be calibrated on a periodic basis. The duration of the calibration cycle shall be no more than two years.

7.3 *Data Acquisition System*—A data acquisition system is required to provide signal conditioning for the sensors and to record the sensor output during a test. The system shall have a minimum sampling rate of 10 000 Hz for each transducer channel.

7.4 *Signal Processing*—Unless otherwise specified in the individual performance standard, the data collected during a test shall be processed as follows prior to any calculations:

7.4.1 *Nine Accelerometer Package (NAP) Signal Processing*—Each accelerometer data channel shall be filtered using either a digital or analog filter which complies with SAE J211 CFC 1000. Data filtering shall occur before any calculations are performed.

7.4.2 *Triaxial Linear Accelerometer and ARS Signal Processing*—Each linear accelerometer data channel shall be filtered using either a digital or analog filter which complies with SAE J211 CFC 1000. Each angular rate sensor data channel shall be filtered using either a digital or analog filter which complies with SAE J211 CFC 180.

8. Calculations

8.1 Upon completion of data collection and signal processing (for example, filtering) for a given impact, the following calculations may be made:

8.1.1 *Impact Test Duration*—Determine the duration of the impact event. Review the three dimensional linear acceleration data from the center of gravity of the headform and determine which is the dominant channel. This is typically the accelerometer that is oriented in the direction of impact, but may also be determined by the channel having the highest peak value during the loading phase of the test. Data associated with any secondary interactions of the headform with the carriage or end of rebound travel are not to be used in determining the test duration. Test duration is the time from the initiation of impact (t1) until this dominant channel returns to or crosses 0 g (t2).

8.1.2 *Peak Resultant Linear Acceleration*—The resultant acceleration is calculated by summing the squares of the component orthogonal linear accelerations as measured at the center of gravity of the test headform at each time interval and then taking the square root at each time step.

[7] Padgaonkar, A.J., Krieger, K.W., and A.I. King. "Measurement of Angular Acceleration of a Rigid Body Using Linear Accelerometers". *J. Applied Mechanics*42, pp. 552-556, 1975.