Tennis Ball Stiffness and Durability

E59 Project

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Abstract

Changes to tennis balls stiffnesses were compared after individual wearing regimens of 20, 40, 50, 55, 70, and 80 impacts at either 37 or 45 mph. The 45 mph impact speed was found to consistently soften balls to a greater degree than the 37 mph impact speed. Additionally, further impacts oscillated between softening and hardening the balls, while the balls as an overall trend progressively softened. These results are likely due to a combination of accelerated internal pressure loss and the effect of impact on the polymer molecules that make up the rubber core of the ball.
Introduction

As properties of tennis balls have become better defined in the past several years, the International Tennis Federation or ITF, as well as other leading sports researchers, have begun to study the durability of tennis balls. On the professional level, the degradation of tennis balls due to match wear is typically corrected for by replacing the six balls used at any one time in a match with new balls after every nine games of play. On the US collegiate level, the three balls used are replaced with fresh balls after every set (minimum of six games) for division one play and every two sets (minimum of twelve games) for division two and three play. Due to the absence of a strict ITF standard, these ball change standards are based largely on a compromise between fiscal reasonability and tennis players’ “feel” for changes to the ball.

Along with qualities such as texture and bounce height, a player’s “feel” is largely based on the stiffness of the ball, which is generally thought to decrease slowly over play. Stiffness plays a large role in a player’s “feel”, as the server will often select which ball to serve based on a quick squeeze test of potential balls. Balls with greater stiffness contact the racket for less time during a hit than softer balls, resulting in a significant difference in control and reaction forces felt by the player’s arm. For particularly soft balls, such forces can lead to injury such as tennis elbow. Despite the significant effect of change in ball stiffness on play, little research has been done to investigate how or why the stiffness of the tennis ball changes over play, with one major exception being a 2003 study by Capel-Davies and Miller of the ITF.

Technical Discussion

For a specific brand of tennis ball to be approved for use in an ITF standardized game of tennis, it must pass five standard ITF approval tests, including those for return and forward deformation, the two components of the approval testing that test ball stiffness. The ITF deformation tests (shown in Figure 1) consist of the following steps: a load of 18 lbs is applied to the tennis ball and deformation of the diameter of the ball is measured and recorded. This is the forward deformation. The ball is then loaded to a deformation of 1 inch, after which the load is smoothly removed back to 18 lbs and again
the deformation (this time termed the return deformation) is measured. This is repeated on three mutually perpendicular axes, and the mean is recorded. The standard machine for the deformation test is an automated deformation testing device created by the ITF.

The ITF specifies that, after being acclimatized for 24 hours prior to testing, the approval tests occur in a room with approximately the following conditions: 68° F, 60% relative humidity, and 30 inches Hg of atmospheric pressure. Furthermore, the ITF specifies that each ball should be pre-compressed to reduce any uneven deformation or set in the ball directly before the first approval test. This consists of loading the ball to 1 inch of deformation along three mutually perpendicular axes consecutively, and then repeating this process 2 more times for 9 total compressions. For more detail of approval testing please consult Appendix C.

In 2003, using ball approval tests, Capel-Davies and Miller published data for the change in tennis balls’ forward deformations and return deformations as well as several other properties after wearing three types of tennis balls in a testing rig. The rig fired tennis balls at approximately 20 m/s (~44.7 mph) at a 15° incline onto a rough, acrylic surface. Each shot was intended to replicate the wear of a professional level hit. Balls were initially acclimatized and put through the pre-compression, mass, deformation, and rebound portions of the ITF ball approval test, then worn for 50 cycles and tested again after 30 minutes of rest. This process was repeated 3 times for a total of 150 cycles of wear and four sets of approval tests. The data was then analyzed to determine the effects of the wearing process and the effects of the testing process on the different types of balls. For stiffness, Capel-Davies concluded that wearing increases both forward and return deformation, or softens balls, as shown in Figures 2 and 3, with the majority of the
change occurring within the first 50 impacts.

Figure 2: ITF 2003 Results for Forward Deformation

Figure 3: ITF 2003 Results for Return Deformation
These results are supported by the 2006 work of Cubitt and Bramley of the University of Bath, who claim that the major contributor to ball softening is air leaking out of tennis balls’ rubber cores. They assert that because of the low-density polymers used in tennis ball cores, the balls are relatively permeable by liquids and gases. Internal pressure is lost by diffusion, adsorption, and desorption, with the latter two also contributing to the degradation of the mechanical properties of the rubber cores, leading to more rapid pressure loss. The low density of the polymers allows surrounding mediums with moveable molecules to permeate the core’s molecular structure. This stress-creating process causes tiny cracks to form, which propagate, resulting in more rapid pressure loss and ball softening.

**Experimental Setup and Procedure**

The experimental procedure was carried out in three separate two-day testing sequences. The first day consisted of wearing the tennis balls by shooting the balls against a painted concrete wall. Approximately 24 hours later, the balls were put through adaptations of the pre-compression and deformation test portions of the ITF ball-approval testing.

It should be noted that while, for feasibility purposes, the testing procedure for this project did not follow the ITF ball approval standards very precisely, the procedure was kept consistent between test days. For instance, the compression method was slower than that specified in the standards, and the balls were not tested under perfect, lab-controlled atmospheric conditions. Because of these discrepancies, results cannot be measured directly to those from true ball approval tests. However, because test methods are consistent from ball to ball and from day to day, and because the results are measured in stiffness changes from control balls exposed to identical atmospheric conditions, the results accurately show the relationship between velocity of impact, number of impacts, and ball stiffness, which is the goal of this project.
**Wearing Setup**

To wear the balls, a Tennis Tutor Jr. tennis ball machine was first calibrated with a JUGS cordless mph radar gun. The ball machine, run off of a power cord, was then placed approximately 15.5 in. from a painted concrete wall as shown in Figure 4. A lacrosse net was then set up behind the machine for safety and to facilitate ball collection.

**Wearing Procedure**

On each day designated for wearing, six cans of balls were opened, marked with identification codes, and scrambled. Three balls were then selected at random to be the control balls, while the remaining balls were placed in the ball machine. The machine was then set to the appropriate launching speed and run until all the balls had been shot once. The machine was then turned off while the balls were collected, and reloaded, after which the machine turned on for another cycle. This process was repeated, removing three balls from circulation after 20, 40, 55, 70, and $80^1$ impacts. The balls were then transferred to a closed Styrofoam box and transported to a location to be acclimatized at a standard temperature, pressure, and humidity.

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$^1$ For the test day at 45 mph, minor machine fatigue necessitated the removal of three balls after 50 impacts and stoppage of testing after 70 impacts. This ensured the validity of the results by giving the machine more rest.
**Pre-compression**

To approximate ITF pre-compression, a wooden frame, as shown in Figure 5, was created with a thickness one inch less than the mean tennis ball diameter. The wood was then placed on a concrete floor and a tennis ball was placed in the center of a circular opening in the wood. A steel plate was then placed over the ball and body weight applied smoothly until the plate was flush with the wood. The plate was then removed and the ball was rotated to compress perpendicular axes. This was repeated for 9 total compressions on 3 mutually perpendicular axes, as per ITF specifications.

**Testing Setup**

To approximate the ITF forward and return deformation tests, a testing rig was created by attaching steel plates to a crank-operated testing machine as shown in Figure 6. The wooden frame used in pre-compression was reused in this apparatus to provide a clear indication of when the ball had been deformed by one inch. An attached load gage above the top steel plate measured load, which was then read off of a P-3500 Portable Strain Indicator. Deformation was read off of a dial.
gage next to the testing column as shown in Figure 7.

**Testing Procedure**

After every ball had been pre-compressed, one ball at a time was loaded into the testing machine. The top plate was then lowered so as to just touch the ball, and the dial gage zeroed. The ball was then smoothly compressed until under an 18 lbs load, at which point deformation was read off of the dial gage to determine forward deformation. The ball was then compressed until the upper plate was flush against the wood, and then smoothly reduced back to 18 lbs and deformation read and recorded again to find return deformation. This process was repeated on three mutually perpendicular axes for each ball.

![Figure 7: Testing Setup Close Up](image)
Results and Discussion

Of the three wearing velocities attempted, only two of them (37 mph and 45 mph) provided the valid data seen in Figures 8 and 9. The first wearing day (at 53 mph) was corrupted by excessive machine wear, as the machine was only rested after every 5 rounds of shots. This was insufficient, as the machine runs off of battery power even when plugged in and concurrently used. As a result, on the first day of testing, the battery power ran out faster than the wall outlet could charge the battery. This is not exceedingly surprising when one considers that the machine takes over 15 hours to fully charge. The issue of machine fatigue was accounted for in the second two days of testing, which provided the results below. These two graphs plot the mean of nine total data points (3 balls at each sampling point and 3 axes per ball) for each particular combination of velocity and number of impacts. In a few instances, data points were omitted because they were significantly distanced from all other data points at a particular velocity / number of impacts combination. Additionally, data for one entire ball was discarded because all of its values showed much greater deformation than the other two balls for that velocity and number of impacts. Original test data can be seen in Appendix A.

Change in Forward Deformation

![Graph showing change in forward deformation for 45 mph and 37 mph velocities](image)

Figure 8: Change in Forward Deformation
From Figures 8 and 9, it is immediately evident that the balls shot at the higher velocity are less stiff than those shot at the lower velocity. With only one major exception, all data points for balls shot at 45 mph are less stiff than their counterparts shot at 37 mph, which clearly indicates that greater impact speeds soften balls more than lower impact speeds. This is quite logical from the prospective of pressure loss causing reduced stiffness: greater impact velocities will deliver more energy to the collision with the wall, which will create more numerous and larger microcracks in the rubber core, allowing air to escape at a more rapid rate. The loss of pressure then causes a similar loss in stiffness.

The second trend shown in Figures 8 and 9 is the oscillation that occurs between stiffening and softening as the number of impacts is increased, with an overall trend towards becoming less stiff, just as in the 2003 ITF study. This phenomenon is not nearly as straightforward as the relationship between impact velocity and stiffness, due in large part to the complexity of the rubber that makes up tennis balls cores. Theoretically,
tennis balls have two major modes of changing stiffness: changes to the internal pressure of the ball, and changes to the material making up the rubber core of the ball. As the pressure change in the ball is only likely to be a pressure loss with repeated impacts, the general trend of balls softening can be attributed to a slow leaking of air that causes a drop in internal pressure. The oscillating nature of hardening and softening then must be attributed to the more complex changes in the material itself.

The rubber cores, consisting mainly of vulcanized natural rubber, are comprised of many polymer molecules, which have a tendency to coil as opposed to stretching into straight lines. This coiling causes molecules to get tangled together, increasing the stiffness of the rubber. Similarly, if the polymer chains straighten out, as they often do in tension, then the stiffness of the rubber decreases. Additionally, under certain circumstances, chains have the ability to chemically bond to each other creating cross-links, which act as a more stable form of entanglement and stiffens the rubber. Such a chemical reaction can be induced when the necessary activation energy is supplied through exposure to UV rays or heat. The impact of a tennis ball with a concrete wall creates enough heat to allow such a reaction to happen, but it also has enough impact energy to break said bonds. Additionally, the tension and compression that impact creates on various parts of the ball is significant enough to both entangle and straighten polymers. As such, it is difficult to pin point exactly why this processes lines up to oscillate between stiffening and softening the ball, and so the determination of the cause of the oscillation will have to be left to future work, focused on the material changes from a more chemically-focused perspective.

Finally, attention should be called to the data point in the return deformation graph for 20 impacts at 37 mph. This point is the only major data point out of twenty total points that does not fit the oscillation pattern. It is probably a representation of the error inherent to the testing process adding constructively. The major inaccuracies of testing were all known from before the testing ever started: compression speed wouldn’t be uniform, the P-3500 was only accurate to the pound, and the top plate, off of which deformation was measured, wobbled when the hand crank was turned. Recognition of these sources of error from the beginning of testing led to a conscious effort to perform the testing as uniformly as possible, and to disregard any individual data points that
deviated drastically from the mean. To address the testing speed concern, timing was practiced such that deformation times were consistent within about two seconds. P-3500 accuracy was addressed by ceasing to turn the hand crank about a quarter turn past when the P-3500 first read 18 lbs. Wobble was accounted for by using the same gentle two-handed turning method throughout testing. By being as consistent as humanly possible, the hope was that any machine error would add destructively, leaving accurate results. This methodology appears to have worked reasonably well as only one of twenty major data points appears significantly flawed.

Conclusions

Faster impact velocities consistently soften balls to a greater degree than their slower velocities, probably by creating larger microcracks in the tennis ball’s rubber core, from which internal pressure is more rapidly lost. Additionally, further impacts oscillate between softening and stiffening the balls, while the balls, as an overall trend, progressively soften. This overall trend is likely a result of pressure loss, while the oscillations are due to the complicated impact interactions of the low-density polymer molecules that make up the rubber core of the ball.
Acknowledgements

-Professor Faruq Siddiqui for insightful feedback and direction
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References


## Appendices

### Appendix A: Test Data

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Appendix B: Presentation Slides
**PROCEDURE OVERVIEW**

- **Wearing**
  - Setup testing machine and safety net, opened cans
  - Ran one cycle, turned off machine, reloaded machine
  - Repeated process, removing balls after certain numbers of impacts

- **Testing**
  - Setup testing apparatus
  - Pre-compressed all balls
  - Preformed ITF deformation test one ball at a time

**WEARING SETUP**

**WEARING PROCESS**

**PRE-COMPRESSSION**

- Ball compressed to a deformation of one inch on three mutually perpendicular axes
- Repeated three times for nine total compressions
- Intended to remove set from the ball
DEFORMATION TESTS
- Each ball was loaded with 18 lbs and measured deformation of 1 in.
- The load was then reduced to 18 lbs and measured (return deformation)

RESULTS: FORWARD DEFORMATION
- Change in Forward Deformation

DEFORMATION TEST SETUP

ITF STUDY: FORWARD DEFORMATION
- Force vs. Deflection
CONCLUSIONS

- Greater impact speed increases ball softness.
- Increasing impact oscillates between softening and hardening balls.
- Although this oscillation occurs, greater numbers of impacts tend to increase ball softness agreeing with the 2003 ITF study.

SOURCES OF ERROR

- Wear
- Machine fatigue
- Non-ideal environmental conditions
- Non-ideal environmental conditions
UNFINISHED TASKS / FUTURE WORK

- Testing at smaller impact intervals and at a greater variety of speeds
- Testing balls of equal wear exposed to different environmental condition
- Expanding testing to different types and brands of balls

LESSONS LEARNED

- How a specific tennis ball wears with respect to impact velocity and number of impacts
- How to adjust on the fly
- How to communicate more effectively with those whom I need favors from

REFERENCES

Appendix C: ITF Testing Standards

(ii) **THE RULES OF TENNIS – RULE 3 AND APPENDIX I – THE BALL**  
(Effective 1 January 2008)

Balls, which are approved for play under the Rules of Tennis, must comply with the specifications in Appendix I.

The International Tennis Federation shall rule on the question of whether any ball or prototype complies with Appendix I or is otherwise approved, or not approved, for play. Such ruling may be taken on its own initiative, or upon application by any party with a bona fide interest therein, including any player, equipment manufacturer or National Association or members thereof. Such rulings and applications shall be made in accordance with the applicable Review and Hearing Procedures of the International Tennis Federation (see Appendix VI).

The event organisers must announce in advance of the event:

a. The number of balls for play (2, 3, 4 or 6).
b. The ball change policy, if any.

Ball changes, if any, can be made either:
i. After an agreed odd number of games, in which case, the first ball change in the match shall take place two games earlier than for the rest of the match, to make allowance for the warm-up. A tie-break game counts as one game for the ball change. A ball change shall not take place at the beginning of a tie-break game. In this case, the ball change shall be delayed until the beginning of the second game of the next set; or

ii. At the beginning of a set

If a ball gets broken during play, the point shall be replayed.

*Case 1: If a ball is soft at the end of a point, should the point be replayed?*

*Decision: If the ball is soft, not broken, the point shall not be replayed.*

*Note: Any ball to be used in a tournament which is played under the Rules of Tennis, must be named on the official ITF list of approved balls issued by the International Tennis Federation.*

**APPENDIX I – THE BALL**

a. The ball shall have a uniform outer surface consisting of a fabric cover and shall be white or yellow in colour. If there are any seams they shall be stitchless.

b. More than one type of ball is specified. The ball shall conform to the requirements shown in the table below.

c. All tests for rebound, size and deformation shall be made in accordance with the regulations below.
<table>
<thead>
<tr>
<th></th>
<th>TYPE 1 (FAST)</th>
<th>TYPE 2 (MEDIUM)</th>
<th>TYPE 3 (SLOW)</th>
<th>HIGH ALTITUDE</th>
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<tr>
<td>WEIGHT (MASS)</td>
<td>1.975-2.095 oz (56.0-59.4 g)</td>
<td>1.975-2.095 oz (56.0-59.4 g)</td>
<td>1.975-2.095 oz (56.0-59.4 g)</td>
<td>1.975-2.095 oz (56.0-59.4 g)</td>
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<tr>
<td>SIZE</td>
<td>2.575-2.700 inches (6.541-6.858 cm)</td>
<td>2.575-2.700 inches (6.541-6.858 cm)</td>
<td>2.790-2.875 inches (6.985-7.303 cm)</td>
<td>2.575-2.700 inches (6.541-6.858 cm)</td>
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<td>REBOUND</td>
<td>53-58 inches (135-147 cm)</td>
<td>53-58 inches (135-147 cm)</td>
<td>53-58 inches (135-147 cm)</td>
<td>48-53 inches (122-135 cm)</td>
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<tr>
<td>FORWARD DEFORMATION</td>
<td>0.195-0.235 inches (0.495-0.597 cm)</td>
<td>0.220-0.290 inches (0.559-0.737 cm)</td>
<td>0.220-0.290 inches (0.559-0.737 cm)</td>
<td>0.220-0.290 inches (0.559-0.737 cm)</td>
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<tr>
<td>RETURN DEFORMATION</td>
<td>0.265-0.360 inches (0.673-0.914 cm)</td>
<td>0.315-0.425 inches (0.803-1.080 cm)</td>
<td>0.315-0.425 inches (0.803-1.080 cm)</td>
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Notes:

1. This ball may be pressurised or pressureless. The pressureless ball shall have an internal pressure that is no greater than 1 psi (7 kPa) and may be used for high altitude play above 4,000 feet (1,219 m) above sea level and shall have been acclimatised for 60 days or more at the altitude of the specific tournament.

2. This ball is also recommended for high altitude play on any court surface type above 4,000 feet (1,219 m) above sea level.

3. This ball is pressurised and is an additional ball specified for high altitude play above 4,000 feet (1,219 m) above sea level only.

4. The deformation shall be the average of a single reading along each of three perpendicular axes. No two individual readings shall differ by more than .030 inches (.076 cm).

**REGULATIONS FOR MAKING TESTS**

i. Unless otherwise specified all tests shall be made at a temperature of approximately 68° Fahrenheit (20° Celsius), a relative humidity of approximately 60% and, unless otherwise specified, an atmospheric pressure of approximately 30 inches Hg (102 kPa). All balls shall be removed from their container and kept at the recognised temperature and humidity for 24 hours prior to testing, and shall be at that temperature and humidity when the test is commenced.

ii. Other standards may be fixed for localities where the average temperature, humidity or average barometric pressure at which the game is being played differ materially from 68° Fahrenheit (20° Celsius), 60% relative humidity and 30 inches Hg (102 kPa) respectively.
Applications for such adjusted standards may be made by any National Association to the International Tennis Federation and, if approved, shall be adopted for such localities.

iii. In all tests for diameter, a ring gauge shall be used consisting of a metal plate, preferably non-corrosive, of uniform thickness of one-eighth of an inch (0.318 cm). In the case of Ball Type 1 (fast speed) and Ball Type 2 (medium speed) balls there shall be two circular openings in the plate measuring 2.575 inches (6.541 cm) and 2.700 inches (6.858 cm) in diameter respectively. In the case of Ball Type 3 (slow speed) balls there shall be two circular openings in the plate measuring 2.750 inches (6.985 cm) and 2.875 inches (7.303 cm) in diameter respectively. The inner surface of the gauge shall have a convex profile with a radius of one-sixteenth of an inch (0.159 cm). The ball shall not drop through the smaller opening by its own weight in any orientation and shall drop through the larger opening by its own weight in all orientations.

iv. In all tests for deformation conducted under Rule 3, the machine designed by Percy Herbert Stevens and patented in Great Britain under Patent No. 230250, together with the subsequent additions and improvements thereto, including the modifications required to take return deformations, shall be employed. Other machines may be specified which give equivalent results to the Stevens machine and these may be used for testing ball deformation where such machines have been given approval by the International Tennis Federation.

v. The procedure for carrying out tests is as follows and should take place in the order specified:

a. Pre-compression – before any ball is tested it shall be steadily compressed by approximately one inch (2.54 cm) on each of three diameters at right angles to one another in succession; this process to be carried out three times (nine compressions in all). All tests are to be completed within two hours of pre-compression.

b. Weight (mass) test.

c. Size test (as in paragraph iii. above).

d. Deformation test – the ball is placed in position on the modified Stevens machine so that neither platen of the machine is in contact with the cover seam. The contact weight is applied, the pointer and the mark brought level, and the dials set to zero. The test weight is placed on the beam in a position that is equivalent to a load of 18 lb (8.2 kg) on the ball, after which the wheel is turned at a uniform speed such that five seconds elapse from the instant the beam leaves its seat until the pointer is brought level with the mark. When turning ceases the reading is recorded (forward deformation). The wheel is turned again until figure ten is reached on the scale (one inch [2.54 cm] deformation). The wheel is then rotated in the opposite direction at a uniform speed (thus releasing pressure) until the
beam pointer again coincides with the mark. After waiting ten seconds, the pointer is adjusted to the mark if necessary. The reading is then recorded (return deformation). This procedure is repeated on each ball across the two diameters at right angles to the initial position and to each other.

e. Rebound test (as above) – the ball is dropped from 100 inches (254 cm) onto a smooth rigid and horizontal surface. Measurements of both drop height and rebound height are to be taken from the surface to the bottom of the ball.

**CLASSIFICATION OF COURT PACE**

The ITF test method used for determining the pace of a court surface is test method ITF CS 01/02 (ITF Court Pace Rating) as described in the ITF publication entitled “ITF guide to test methods for tennis court surfaces”.

Court surfaces which have an ITF Court Pace Rating of 0 to 29 shall be classified as being Category 1 (slow pace). Examples of court surface types which conform to this classification will include most clay courts and other types of unbound mineral surface.

Court surfaces which have an ITF Court Pace Rating of 30 to 34 shall be classified as being Category 2 (medium-slow pace), while court surfaces with an ITF Court Pace Rating of 35 to 39 shall be classified as being Category 3 (medium pace). Examples of court surface types which conform to this classification will include most acrylic coated surfaces plus some carpet surfaces.

Court surfaces with an ITF Court Pace Rating of 40 to 44 shall be classified as being Category 4 (medium-fast pace), while court surfaces which have an ITF Court Pace Rating of 45 or more shall be classified as being Category 5 (fast pace). Examples of court surface types which conform to this classification will include most natural grass, artificial grass and some carpet surfaces.

**Case 1: Which ball type should be used on which court surface?**

**Decision:** 3 different types of balls are approved for play under the Rules of Tennis, however:

a. **Ball Type 1** (fast speed) is intended for play on slow pace court surfaces

b. **Ball Type 2** (medium speed) is intended for play on medium-slow, medium and medium-fast pace court surfaces

c. **Ball Type 3** (slow speed) is intended for play on fast pace court surfaces
(iii) SPECIFICATIONS FOR STAGE 1, 2 AND 3 TENNIS BALLS

Tennis balls have been developed to increase the speed at which beginner and recreational children and adult players learn the game, which thus enhances their enjoyment of tennis. This has been achieved by the manufacture of tennis balls which are designed to be ‘slower’ and which therefore allow greater opportunity for players to rally.

Three such groups of balls have been introduced: Stage 3 (red), Stage 2 (orange) and Stage 1 (green). The specifications, with effect from 21 September 2007, are:

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<th>Introductory balls (standard construction)</th>
<th>Standard ball</th>
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<tr>
<td></td>
<td>Stage 3 (red)</td>
<td>Stage 2 (orange)</td>
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<tr>
<td>Size</td>
<td>2.72-3.15 inches (6.90-8.00 cm)</td>
<td>2.362-2.700 inches (6.000-6.858 cm)</td>
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<tr>
<td>Mass</td>
<td>32.0-42.0 grams</td>
<td>36.0-46.9 grams</td>
</tr>
<tr>
<td>Rebound height</td>
<td>37.4-43.3 inches (95-110 cm)</td>
<td>39.4-45.3 inches (118-115 cm)</td>
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<tr>
<td>Forward deformation</td>
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<td>0.551-0.650 inches (1.400-1.650 cm)</td>
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Notes:
There is currently no specification for return deformation.
There is currently no limit on the difference between individual forward deformation readings.

All tests for size, mass, rebound height and forward deformation should be carried out in accordance with the official procedures described in Appendix 1 of the Rules of Tennis.

There are 3 sub-categories of Stage 3 (red) ball:
1. Standard construction (as specified above).
2. Cut foam.
3. Moulded foam.

Due to the high compressibility of cut foam and moulded foam Stage 3 (red) balls, ITF approval is obtained initially through play testing by a panel of experts and a laboratory test, and thereafter by laboratory testing only, making comparison against results of the previous year(s).

Information regarding approval of all introductory balls can be obtained from the ITF Technical Centre. The list of 2008 ITF Approved Stage 1, 2 and 3 tennis balls is published in Section A of this booklet.
(iv) ISO 9001:2000

All testing, administration and calibration procedures adopted by the ITF Technical Centre in testing tennis balls for ITF Approval, and court surfaces for ITF Classification, are carried out and managed according to ISO 9001:2000.

(v) FUTURE DEVELOPMENT OF TESTING METHODS, TENNIS BALL SPECIFICATIONS AND COURT PACE RATING VALUES

The ITF reserves the right to amend and update the information given in this document without prior notice. As a general rule, amendments will be made only after consultation with interested parties.
PART A – THE BALL

1. PROCEDURES AND GUIDELINES FOR THE TESTING OF TENNIS BALLS FOR ITF APPROVAL

The properties of tennis balls are specified by the International Tennis Federation to generate uniformity, and consistency in performance. Special testing facilities and apparatus are necessary to accurately measure these properties, and this section details the required test conditions and procedures.

The following notes are provided as additional information for those involved in the testing or evaluation of tennis balls and should be read in conjunction with the specification for a tennis ball and regulations for making tests, as described in Rule 3 and Appendix 1 of the Rules of Tennis.

1.1 General Considerations

A tennis ball consists of a hollow rubber core (which may or may not be pressurised) covered by a textile material composed of wool, nylon and cotton. Because the properties of the rubber core and its internal gas are affected by temperature, the properties of the cover by atmospheric moisture and the effective internal pressure by the external atmospheric pressure, it is important that ball testing is carried out in a controlled atmosphere where at least temperature and humidity are standardised. It is not practical to control atmospheric pressure, which is primarily dependent on altitude and so it is desirable that any testing station should be at or near sea level so that test data are comparable. In any case, atmospheric pressure should always be recorded when ball tests are made.

The following conditions are specified for testing by the ITF:

- Temperature: 20°C (68°F)
- Relative humidity: 60%
- Atmospheric pressure: 30 inches Hg (760 mm)

While no tolerances are given in the specification contained in the Rules of Tennis, limits of ±2°C for temperature, ±5% for humidity and ±25 mm Hg have been established.

1.2 Environmental Conditions

To meet the environmental requirements noted above, a well-insulated room with double-glazed windows not exposed to sunshine, and a double-door 'air-lock' arrangement to reduce air leakage on entry and exit, are recommended.
Control of temperature and humidity should be provided by a temperature and humidity control unit of an appropriate specification with regard to thermal capability and control accuracy. Such a conditioner normally consists of two component parts: an internal fan unit and an external condenser unit with connecting piping.

The specification of this conditioning equipment is primarily related to removing excess heat and moisture generated within the environment by electrical equipment and the bodies of the technicians working there. Such equipment must be capable of controlling the testing environment within the tolerances set down in Section 1.1.

As well as controlling the environment, it should also be independently monitored, and so temperature and humidity recorders together with a barometer are necessary. A permanent record of environmental conditions during conditioning and test should be kept.

Balls selected for testing should be stored under such controlled conditions and exposed to circulating air for ‘conditioning’ for the required 24 hours prior to testing.

1.3 Laboratory and Test Equipment

Mass – Test Method ITF TB 01/01: An electronic laboratory balance measuring in grams to at least two decimal places, to a capacity of 100 grams.

Size – Test Method ITF TB 02/01: Equipment consists of two circular gauges defining the limits of ball diameter designated ‘Go/No-Go’ through which a ball will drop/not drop under its own weight. See Figure 1.

Deformation – Test Method ITF TB 03/01: This is measured using a ‘modified’ Stevens Machine.

Prior to deformation testing the ball must be pre-compressed three times on each of 3 perpendicular axes through a distance of one inch (2.540 cm) in order to remove any ‘set’ in the ball. One pre-compression should occur on each axis in succession, until 9 pre-compressions in all are completed. This is carried out on a ‘pre-compression jig’. See Figure 2.
Ball Type 1 and Type 2
(1) A ball must pass through a ring gauge with internal diameter 2.700 inches (6.858 cm) under its own weight.
(2) A ball must not pass through a ring gauge with internal diameter 2.575 inches (6.541 cm) under its own weight.

Ball Type 3
(1) A ball must pass through a ring gauge with internal diameter 2.875 inches (7.302 cm) under its own weight.
(2) A ball must not pass through a ring gauge with internal diameter 2.750 inches (6.985 cm) under its own weight.

Figure 1. Size – Test Method ITF TB 02/01.

Figure 2. Pre-Compression – Test Method ITF TB 03/01.

Rebound - Test Method ITF TB 04/01: This consists of dropping a ball through a height of 100 inches (254 cm) (measured from the bottom of the ball) onto a rigid block of high mass and measuring the rebound height (again measured to the bottom of the ball). The method adopted by the ITF to accurately measure the ball rebound...
height involves automatic tracking of the rebound by computer software. See Figure 3.

![Diagram of rebound test setup](image)

**Figure 3. Rebound – Test Method ITF TB 04/01**

To increase the accuracy of the rebound measurement and to reduce the effects of parallax, a shadow of the ball produced by a parallel beam of light is cast onto a frosted screen incorporating a graduated calibrated scale. The resulting image is recorded by a video camera together with indication of the reference number of the ball and bounce number being tested. Software records the images generated by the camera and tracks the trajectory of the ball, recording its highest point with reference to the calibrated scale.

### 1.4 Test Procedure

The ITF requires that 6 dozen balls are submitted for approval and from these the ITF randomly selects 2 dozen balls for testing. The ball containers are opened and the balls are then stored on racks in the controlled environment for a minimum of 24 hours prior to testing. Each ball should be individually marked (preferably with a permanent marker) so that test results can be assigned to a particular ball.

Following visual inspection, the test procedure should be carried out on each ball in the following sequence:

1. **Pre-compression.** Apply to each of the 3 axes in succession, as described in Section 1.3.
2. **Mass.** Record the mass displayed and round to one decimal place for reporting purposes.
iii. **Size.** Use ‘Go/No-Go’ gauge across at least 3 mutually perpendicular diameters. Care should be taken to ensure that the ball relies only upon its own weight to pass through a ring. Record Pass/Fail.

iv. **Deformation.** Test once on each axis and record the results. Report mean, and maximum difference between readings, for each ball. See also Section 1.3. The test measures the deformation of a ball under a load of 18 pounds (8.165 kg) weight after a small initial load has been applied to compress the fabric cover material. See Figure 4. The ‘deformation’ is measured in two senses:

a. When the load is first applied, i.e. the ‘forward’ deformation.

b. Under the action of the load prior to it being removed and after the ball has been compressed further through a total distance of one inch (2.540 cm) - termed the ‘return’ deformation.

![Diagram of deformation](image)

**Figure 4. Deformation – Test Method ITF TB 03/01**

**Automated compression machine**

The automated compression machine (pictured overleaf) has been developed by the ITF as an alternative to the Stevens machine for testing tennis ball deformation.

The computer-controlled machine replicates the operation of the Stevens machine, but provides significant improvements over the Stevens machine:

a. Elimination of operator error in speed of testing, timing and results tabulation.

b. Reduction of backlash (unmeasured losses in movement due to gaps between cog teeth).
c. Graphical display of useful comparative information such as hysteresis losses.
d. Carousel feed allowing up to 12 balls to be tested in 3 axes without operator assistance.
e. The machine can also be used to pre-compress balls according to the Rules of Tennis.

All of these advantages give the automated machine more functionality, accuracy and better reproducibility of results than the Stevens machine. For further information on the automated compression machines contact the ITF Technical Centre.

v. Rebound. Record four valid measurements per ball (disregarding obvious ‘bad bounces’) and report mean rebound height.

1.5 Tests for Other Ball Properties

The ITF Technical Centre has routinely measured properties of tennis balls other than those required by the Rules of Tennis. These additional tests are carried out as part of the ITF’s policy of improving our understanding and definition of the sport in general and balls in particular.

These tests are carried out on balls submitted to the ITF for ITF Approval testing and on balls obtained by the ITF from markets or tournaments.

Some of the additional properties being measured include:

a. Internal pressure of ball packaging (for pressurised balls). Measurements are taken using a standard pressure gauge with needle attachment and rubber seal. Results are recorded in lb/in².
b. Internal pressure of the ball. It has been established by the ITF Technical Commission that pressureless balls should have an internal pressure of no more than 1 psi. To ensure that this standard is met, all pressureless balls are tested. Measurements are taken using a standard pressure gauge with needle attachment. Results are recorded in lb/in².
c. Durability. In order to develop future specifications for the durability of tennis balls, the ITF is currently re-testing six of the balls submitted for testing 24 hours after the following wearing regime: 20 impacts each at 40 ± 2 m/s onto a smooth, rigid surface (at approximately 90° to the surface) and 2 minutes in a felt-wearing device (two balls at a time).

Manufacturers who require further details of such tests should contact the ITF Technical Centre.

1.6 Calibration

The apparatus used for the various tests must be regularly checked for accuracy of calibration as follows:

Size. The ring gauges should be checked for accuracy against a known traceable reference every two years. The tolerance on ring gauge diameter should be ± 0.0025 inches (0.00635 cm).

Mass. The weighing scales should be checked with calibration weights monthly and to traceable national standards. The accuracy of the scales should be ± 0.001g.

Rebound. Where the ‘video’ system is used for measuring rebound, the horizontal alignment of the light beam must be checked at the beginning and end of each test sequence. The accuracy of drop height and the frosted and transparent scales are checked monthly, to a tolerance of 0.1 inches (0.254 cm).

Deformation. The Stevens machine should be checked daily for beam balance with the contact weight removed. It should be checked also for accuracy of platen displacement twice per year using 60 mm slip gauges. The tolerance on the platen displacement should be ± 0.008 cm. The automated compression machine should be calibrated at six-month intervals using gauge blocks to the same tolerance as the Stevens machine. The automated compression machine should be compared against the Stevens machine monthly.

1.7 Conditions for ITF Approval

A manufacturer who wishes their ball to be considered for inclusion in the list of ITF Approved tennis balls must submit a sample of balls for testing by the ITF in the manner described in detail above. The sample of balls submitted must be found to conform to the Rules of Tennis in all respects.

A ball which passes the requirements of ITF testing and which gains ITF Approval is approved by the ITF only on the basis that it has been found to conform to the current Rules of Tennis and is therefore considered suitable for use in tournaments played according to the Rules of Tennis. ITF Approval does not imply any other form of approval.