Designation: G206 – 17

Standard Guide for
Measuring the Wear Volumes of Piston Ring Segments Run against Flat Coupons in Reciprocating Wear Tests[1]

This standard is issued under the fixed designation G206; 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 guide covers and describes a profiling method for use accurately measuring the wear loss of compound-curved (crowned) piston ring specimens that run against flat counterfaces. It does not assume that the wear scars are ideally flat, as do some alternative measurement methods. Laboratory-scale wear tests have been used to evaluate the wear of materials, coatings, and surface treatments that are candidates for piston rings and cylinder liners in diesel engines or spark ignition engines. Various loads, temperatures, speeds, lubricants, and durations are used for such tests, but some of them use a curved piston ring segment as one sliding partner and a flat or curved specimen (simulating the cylinder liner) as its counterface. The goal of this guide is to provide more accurate wear measurements than alternative approaches involving weight loss or simply measuring the length and width of the wear marks.

1.2 *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.*

1.3 *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 *ASTM Standards:*[2]

G40 Terminology Relating to Wear and Erosion

G181 Test Method for Conducting Friction Tests of Piston Ring and Cylinder Liner Materials Under Lubricated Conditions

3. Terminology

3.1 *Definitions*—See Terminology G40.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *conformal contact, n—in friction and wear testing*, any macro-geometric specimen configuration in which the curvature of one contact surface matches that of the counterface.

3.2.1.1 *Discussion*—Examples of conformal contact include a flat surface sliding on a flat surface and a ball rotating in a socket that conforms to the shape of the ball. A pair of surfaces may begin a wear or friction test in a non-conforming contact configuration, but develop a conformal contact as a result of wear.

3.2.2 *cylinder bore/cylinder liner, n—in an internal combustion engine*, the cylindrical cavity in which the piston moves.

3.2.2.1 *Discussion*—The terms cylinder bore and cylinder liner are used interchangeably in the description of this method. Cylinder liners are most commonly used in heavy-duty engines which are intended to be rebuilt. They are sleeves, generally of a cast iron, which are surrounded on their outer surface by coolant for better heat transfer, and meant to be replaced when excessively worn. A cylinder bore is either machined directly into an engine block or is added as a sleeve (typically of iron) into a block of another material (typically aluminum). The material of the cylinder bore, therefore, may or may not be the same material as the engine block and the inside surface of the bore may or may not have additional surface treatment.

4. Summary of Guide

4.1 A reciprocating wear testing apparatus is used to simulate the back-and-forth motion of a piston ring within a cylinder bore in the presence of a heated lubricant. Depending on the duration and severity of the imposed test conditions, some degree of wear is generally produced on one or both members of the sliding pair. Mathematical models of the wear scar geometry on both the piston ring and cylinder liner surfaces allow the degree of wear to be quantified in terms of volume lost. The contact geometry for such tests, in the context

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

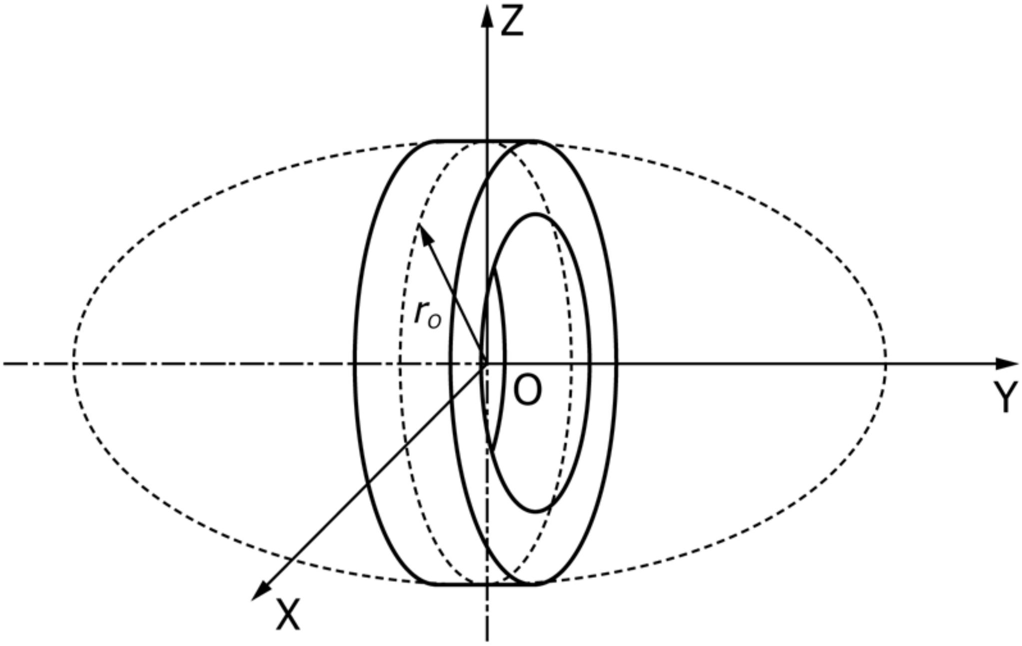

FIG. 1 Schematic Drawing of the Ring

of ring-on-liner frictional behavior, is exemplified in Practice G181. That method uses pre-worn-in surfaces, and therefore it differs from the present case in which wear loss is based on measurements of initial and final profiles of the test specimens.

5. Significance and Use

5.1 The practical life of an internal combustion engine is most often determined by monitoring its oil consumption. Excessive oil consumption is cause for engine repair or replacement and can be symptomatic of excessive wear of the piston ring or the cylinder bore or both. More wear-resistant materials of construction can extend engine life and reduce cost of operation. Although components made from more wear-resistant materials can be tested in actual operating engines, such tests tend to be expensive and time consuming, and they often lead to variable results because of the difficulty in controlling the operating environment. Although bench-scale tests do not simulate every aspect of a fired engine, they are used for cost-effective initial screening of candidate materials and lubricants. The test parameters for those tests are selected by the investigator, but the end result is a pair of worn specimens whose degree of wear needs to be accurately measured. The use of curved specimens, like segments of crowned piston rings, presents challenges for precise wear measurement. Weight loss or linear measurements of lengths and widths of wear scars may not provide sufficient accuracy to discriminate between small differences in wear. This guide is intended to address that problem.

6. Reagents

6.1 *Cleaning Solvents*—Suitable solvents may be used to degrease and clean specimens prior to conducting wear tests and cleaning specimens afterward. No specific solvents are recommended here, except that they should not chemically attack the tested surfaces, nor leave a residual film or stain after cleaning.

7. Apparatus and Specimen Preparation

7.1 *Description of the Test Apparatus*—Any dimensional metrology instrument that is capable of measuring the length, width, and depths of the subject wear scars, and the curvatures of the regions that surround and contain them, may be used. These include stylus-type profiling instruments, optical or laser-based interferometric instruments, and the like. It is the responsibility of the user to ensure that the dimensional measurement apparatus used has been correctly calibrated.

7.1.1 *Specimen Preparation*—The test specimens shall be solvent cleaned and free from debris or other measurement-complicating artifacts.

7.1.2 *Specimen Fixturing*—A suitable fixture shall be used to clamp the specimens in the proper orientation for profiling and dimensional measurement without touching the area subjected or to be subjected to wear.

8. Procedure

8.1 The current procedure, examples of its use, and comparison with other methods for measuring wear, have been published elsewhere.[3] Wear measurements for ring and liner specimens are separately described in the following paragraphs. It is the user's responsibility to determine which of the following procedures best suits the wear scar geometry produced in the reciprocating test method that was used.

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[3] Qu, J., and Truhan, J. J., "An Efficient Method for Accurately Determining Wear Volumes of Sliders with Non-flat Wear Scars and Compound Curvatures," Wear, Vol 261, 7-8, 2006, pp. 848-855.

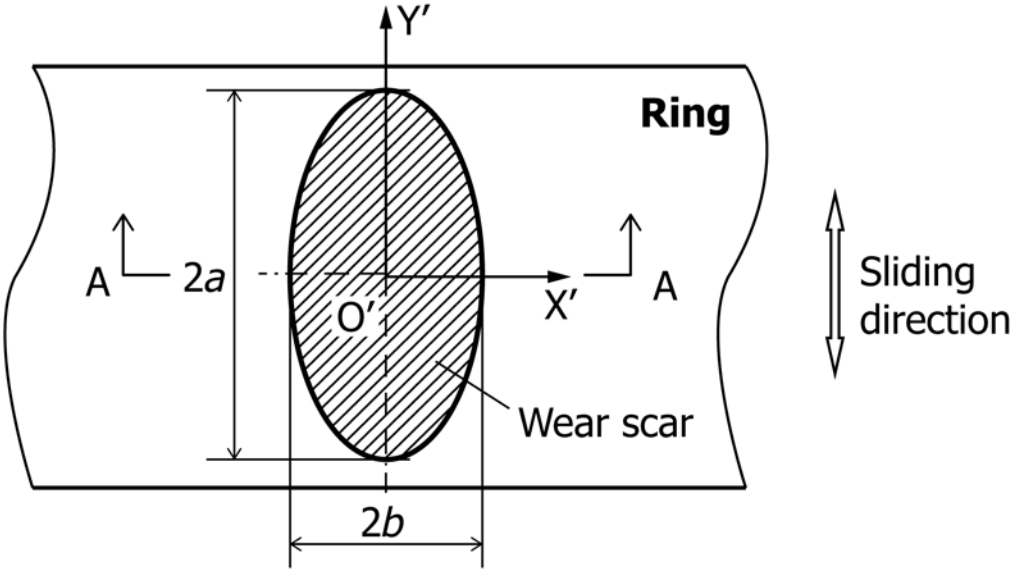

FIG. 2 Schematic Top View of the Wear Scar on the Ring Specimen

8.2 *Wear Volume of the Piston Ring Specimen*—A hypothetical piston ring with compound curvatures can be considered as the central slice of an ellipsoid with initial ring radius r_o as the minor semi-axis, as illustrated in Fig. 1. The worn surface on the ring usually will not be flat but also has compound curvatures. The wear scar can be considered as a patch of another ellipsoid whose minor semi-axis is the final radius r_w on the wear scar. The top view of the wear scar is in elliptical shape with scar length across the crown ($2b$) and scar width in the conferential direction of the ring ($2a$), as shown in Fig. 2. Fig. 3 illustrates the side view of the worn surface, showing the curvature change after testing. By measuring the wear scar size ($2a$ and $2b$) and ring curvatures (r_o and r_w) before and after testing, the wear volume V_{ring} and maximum wear depth h_{ring} can be obtained by the following formulae:

$$V_{ring} = \pi\frac{a}{3b}\left[2r_o^3 - 2r_w^3 - (2r_o^2+b^2)\sqrt{r_o^2 - b^2}+(2r_w^2+b^2)\sqrt{r_w^2 - b^2}\right] \tag{1}$$

$$h_{ring} = r_o - r_w - \sqrt{r_o^2 - b^2}+\sqrt{r_w^2 - b^2} \tag{2}$$

8.2.1 When the ring specimen has much lower wear resistance compared to the flat specimen, the worn surface on ring will be fairly flat and Eq 1 and Eq 2 can be simplified as follows:

$$V_{ring} = \pi\frac{a}{3b}\left[2r_o^3 - (2r_o^2+b^2)\sqrt{r_o^2 - b^2}\right] \tag{3}$$

$$h_{ring} = r_o - \sqrt{r_o^2 - b^2} \tag{4}$$

8.2.2 Please note that when the crown curvature is zero or very small compared to the ring curvature, the wear scar length is restricted by the ring thickness and the above formulae for wear volume calculations will no longer be valid. In this case, the ring surface should be considered as cylindrical, as discussed in 8.2.3.2.

8.2.3 *Special Cases:*

8.2.3.1 *Spherical Ring Surface*—When the two compound curvatures on a ring specimen are identical, the ring will be the central slice of a sphere with a round shape wear scar. The wear volumes and maximum wear depths can be calculated using Eq 1-4 with $a = b$. Note that the calculations in this case can be directly applied to commonly used ball sliders.

8.2.3.2 *Cylindrical Ring Surface*—When the crown curvature is zero or very small compared to the ring curvature, the ring surface should be considered as cylindrical and the wear scar is rectangular with width $2b$ and length equal to the ring thickness $2a = t$. The worn surface is also cylindrical with radius r_w. Although Eq 2 and Eq 9 are still valid for maximum wear depths, different formulae have been derived for wear volumes. Namely:

$$V_{ring} = t\cdot\left(r_o^2 arcsin\frac{b}{r_o} - r_w^2 arcsin\frac{b}{r_w} - b\sqrt{r_o^2 - b^2}+b\sqrt{r_w^2 - b^2}\right) \tag{5}$$

$$V_{flat} = L\cdot\left[r_f^2 arcsin\left(\frac{W}{2r_f}\right) - b\sqrt{r_f^2 - \frac{W^2}{4}}\right] \tag{6}$$

When the ring specimen has far lower wear resistance than the flat specimen, the worn surface on ring will be relatively flat. In that case, the wear volume and maximum wear depth can be calculated by Eq 7 and Eq 4, respectively.

$$V_{ring} = t\cdot\left(r_o^2 arcsin\frac{b}{r_o} - b\sqrt{r_o^2 - b_2}\right) \tag{7}$$

8.3 *Wear Volume of a Flat Counterface Specimen*—A schematic drawing of the wear scar on the flat specimen is illustrated in Fig. 4. L_s is the stroke length of the reciprocating test. The length and width of the wear scar on the flat are denoted as L and W, respectively. The wear scar on the flat is composed of three segments, the cylindrical middle with radius of r_f and the two compound-curvature ends. The wear volume V_{flat} and maximum wear depth h_{flat} can be calculated by

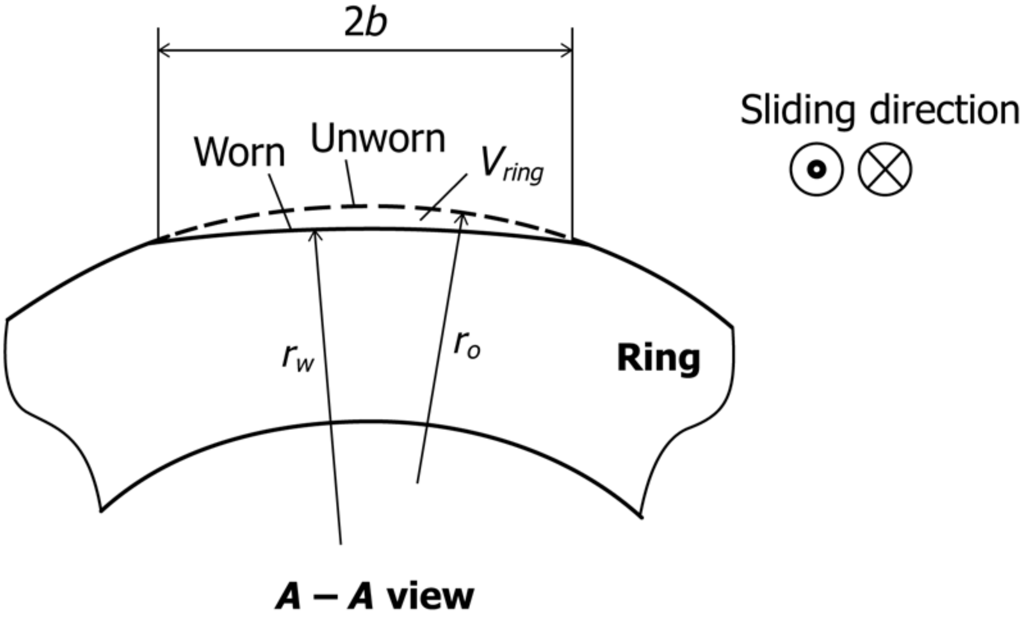

FIG. 3 Schematic Side View of the Wear Scar on the Ring Specimen

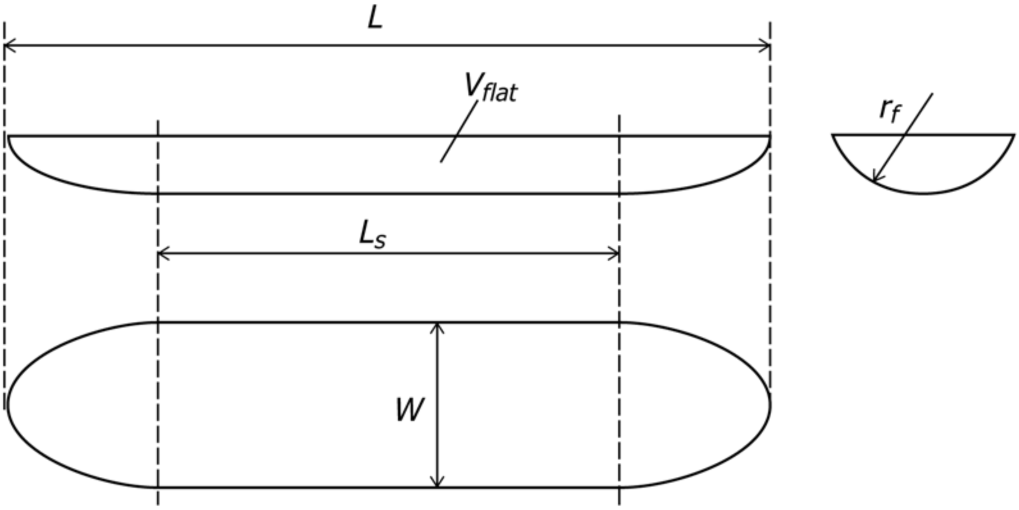

FIG. 4 Schematic Wear Scar on a Flat Specimen

$$V_{flat} = L_s\left[r_f^2 arcsin\left(\frac{W}{2r_f}\right) - \frac{W}{2}\sqrt{r_f^2 - \frac{W^2}{4}} \right] \tag{8}$$

$$+\pi\frac{(L - L_s)}{3W}\left[2r_f^3 - \left(2r_f^2 + \frac{W^2}{4}\right)\sqrt{r_f^2 - \frac{W^2}{4}} \right]$$

$$h_{flat} = r_f - \sqrt{r_f^2 - \frac{W^2}{4}} \tag{9}$$

9. Report

9.1 Wear measurements, expressed as the volume of material lost, shall be reported in accordance with the test method that was used to generate the wear.

9.1.1 In addition to, or in place of the calculated wear volume, data may be normalized to express wear volume loss per unit sliding distance per unit applied normal force, or similar combined parameters, wear rates, or wear factors.

10. Keywords

10.1 cylinder liner; piston ring; wear measurement

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