Designation: G223 – 23

Standard Test Method for Measuring Friction and Adhesive Wear Properties of Lubricated and Nonlubricated Materials Using the Twist Compression Test (TCT)[1]

This standard is issued under the fixed designation G223; 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 laboratory procedures for determining the coefficient of friction (COF) and resistance of materials to adhesion under flat sliding using the twist compression test (TCT). This test method ranks material couples, surface treatments, coatings, and lubricant combinations by COF and their resistance to adhesion.

1.2 The time until adhesion for the materials under the test conditions are reported and used to quantify the tribocouple's adhesion resistance and susceptibility to galling or scuffing. Systems of higher adhesion resistance will give longer time until failure.

1.3 The coefficient of friction values averaged between the test reaching full test pressure and the time of the onset of adhesion or the end of tests run for a predetermined time period are recorded. Systems are ranked by their average coefficients of friction before adhesion occurs.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard except psi and pounds in Table 1.

1.5 *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.*

1.6 *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

3. Terminology

3.1 *Definitions*—Definitions used in this test method are in Terminology G40.

3.1.1 *adhesive wear, n*—wear caused by localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface.

3.1.2 *apparent area of contact, n—in tribology,* the area of contact between two solid surfaces defined by the boundaries of their macroscopic interface.

3.1.3 *galling, n*—form of surface damage arising between sliding solids distinguished by macroscopic, usually localized, roughening and the creation of protrusions above the original surface; it is characterized by plastic flow and may involve material transfer.

3.1.4 *nominal contact pressure, FL^{-2}, n—in tribology,* an average contact pressure between two conforming bodies calculated by dividing the contact force by the apparent area of contact.

3.1.5 *plowing, n—in tribology,* the formation of grooves by plastic deformation of the softer of two surfaces in relative motion.

3.1.6 *scoring, n—in tribology,* a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding.

3.1.7 *scratching, n—in tribology,* the mechanical removal or displacement or both of material from a surface by the action of abrasive particles or protuberances sliding across the surfaces.

3.1.8 *scuffing, n*—form of adhesive wear occurring in inadequately lubricated tribosystems that is characterized by macroscopically observable localized changes in surface texture.

[1] This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.40 on Non-Abrasive Wear.

Current edition approved June 1, 2023. Published July 2023. DOI: 10.1520/G0223-23.

[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.

3.1.9 *sliding wear, n—in tribology,* wear caused by the relative motion in the tangential plane of contact between two solid bodies.

3.1.10 *stick-slip, n—in tribology,* a cyclic fluctuation in the magnitudes of friction force and relative velocity between two elements in sliding contact, usually associated with a relaxation oscillation dependent on elasticity in the tribosystem and a decrease of the coefficient of friction (COF) with onset of sliding or increase in sliding velocity.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coefficient of friction in twist compression testing, CFT, n—in twist compression testing (TCT),* the transmitted torsional force at a specific radius of gyration divided by the applied normal force:

$$\text{CFT(dimensionless)} = F_{\text{torq, Rg=\_}} / F_{\text{n}} \quad (1)$$

where:

$F_{\text{torq, Rg=\_}}$ = transmitted torsional force at radius and R_g and
F_n = normal force.

3.2.2 *radius of gyration, n—in TCT using an annular contact between a flat specimen and a cylindrical specimen of inner radius, R_i, and outer radius, R_o*, the radius of gyration, *Rg*, is defined as:

$$R_g = \frac{1}{2}\sqrt{R_i^2 + R_o^2} \quad (2)$$

This may be approximated by the mean radius defined as:

$$R_{mean} = \frac{(R_o - R_i)}{2} \quad (3)$$

3.2.3 *seizure, n*—localized fusion of metal between the rubbing surfaces of the test pieces that is characterized by a rapid rise in the CFT versus time curve.

4. Summary of Test Method

4.1 The TCT is used to determine the coefficient of friction in twist compression testing, CFT, and adhesion resistance of nonlubricated and lubricated material couples in conformal normal area contacts under continuous unidirectional sliding conditions. While it is most often used to evaluate material couples, surface treatments, coatings, and lubricants for metalworking processes, the TCT has application in other conformal sliding contacts.

4.2 This test method uses laboratory equipment capable of maintaining a constant, compressive load in a cylindrical flat-on-flat geometry and a mechanism that will produce the necessary relative motion between a rotating ring and the fixed flat specimen. The transmitted torsional force is measured between the rotating ring and a flat specimen. The coefficient of friction determined using TCT is referred to as the coefficient of friction in twist compression testing (CFT). The coefficient of friction in twist compression testing is the ratio of the torsional force transmitted from the rotating specimen to the fixed specimen to the applied normal force. The resulting contact area is an annulus with approximately the same macro dimensions as the cylinder end (see Fig. 1). As surface films are removed or, in the case of lubricated tests, the lubricant is depleted, the adhesive nature of the contact surfaces is revealed in both the magnitude of the CFT and in the duration of CFT versus time graph features.

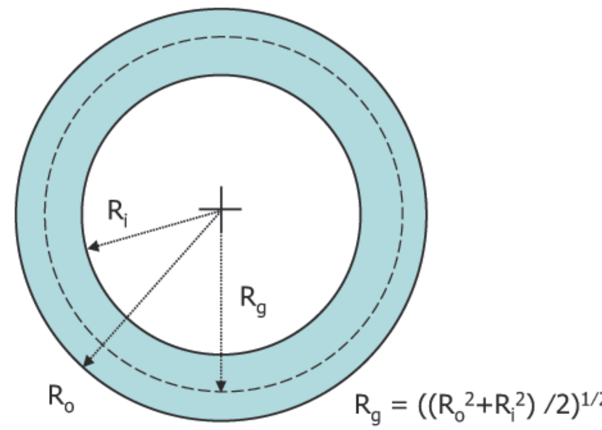

FIG. 1 Radius of Gyration of an Annulus

4.3 The test often ends with the seizure (or cold welding) of the surfaces. This seizure is often characterized by a rapid rise in torque and the CFT versus time curve. Either the annular cylinder or the flat surface may be visually examined to confirm the occurrence of adhesive wear (Fig. 2).

5. Significance and Use

5.1 This test method is designed to rank material couples, surface treatments, and lubricants by CFT and in their resistance to adhesive wear. Since adhesive wear is a complex phenomenon and stochastic in nature, it is essential to evaluate surfaces to confirm the presence of adhesion.

5.2 This test method should be considered when evaluating the impact of changes in a process or application that is prone to adhesive wear, including any combination of scoring, galling, and plowing. These modes of failure commonly occur under sliding contact, at high contact stress, and, when applicable, at lubricant starvation.

5.3 The TCT is often used to evaluate the ability of material couples, surface treatments, coatings, and lubricants to prevent or reduce adhesive wear in metalworking operations including

FIG. 2 TCT Specimens after Testing

deep drawing, extrusion, and pipe bending. Other applications in which the test may be effective are loader bucket bushings, gear teeth at startup, and low-clearance pumps.

5.4 This test method is best used as a comparative screening tool. The ranking of performance produced by the TCT correlates well with the ranking in many applications.[3] However, since the test is a bench test and not directly reproducing any specific application, TCT results should be only used as an indicator of the tendency for adhesive wear to occur. TCT is a useful screening test for comparing the effectiveness of material couples, surface treatments, coatings, and lubricant formulations before process testing and field trials.

6. Apparatus

6.1 The test should be conducted in an instrument sufficiently rigid to minimize elastic deflection under the high loads often used for the test. The test instrument should be capable of providing constant rotational speed, under varying torque, between approximately 5 r/min to 33 r/min for a 25 mm outside diameter (OD) hollow cylindrical specimen with a 3 mm wall thickness (for reference: 0.006 m/s to 0.040 m/s linear speed at radius of gyration). Tests should be carried out at 10 r/min or 0.012 m/s but may be carried out at other speeds. Tests are normally carried out between 7 MPa to 220 MPa nominal contact pressures. The apparatus shall be capable of applying the appropriate pressure with minimum deformation of the frame. Tests are normally carried out under ambient temperature and humidity conditions. Force transducers measure the normal force and torque transmitted from the rotating specimen through the surface contact to the fixed specimen. Optionally, other responses such as acoustic emission, electrical resistance, and temperature may be recorded.

6.2 *Alignment of the Specimens:*

6.2.1 Concentric alignment of the hollow cylinder with the pivot point of the flat specimen or flat specimen holder shall be maintained for a concentric contact path.

6.2.2 Horizontal planar alignment of the contact surfaces of the specimens shall be maintained.

NOTE 1—TCT designs that use ball bearings for alignment shall be checked regularly for flat spots.

7. Reagents and Materials

7.1 *Purity of Reagents*—Reagent-grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.[4] Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Cleaning Fluids*—Test specimens should be cleaned using fluids capable of removing metal preservative coatings that may be present. The cleaning fluid selected should be non-film-forming and not contribute to the friction, load carrying or antiwear properties of the test couple (for example, chlorinated solvents should not be used).

7.3 *Heptane,* laboratory grade.

7.4 *Lint-Free Laboratory Tissues.*

8. Test Specimens

8.1 A schematic of the test configuration is shown in Fig. 3.

8.1.1 *Annular Specimen*—The annular specimen is made from the material of one contacting surface (usually chosen for convenience of fabrication). Specimens can be fabricated on a lathe to produce an annulus with a 25.0 mm ± 0.5 mm OD and a 19.0 mm ± 0.5 mm inside diameter at a 90° angle to the longitudinal axis of the cylinder (see Fig. 3). When evaluating soft material surfaces such as copper, aluminum, or zinc alloys, sharp edges on the cylindrical specimen contact edges may be beveled to <0.25 mm radius to reduce edge effects (chamfered or fillet). The annular specimens shall include a means of being held in the rotating fixture preventing them from turning, relative to the fixture, under torques during the test. The annular specimens are treated as they would be for the application of interest. The annular surface should be flat and free from visible scratches. Edges should be protected during handling to prevent chipping, and specimens with chipped contact edges should not be used in tests.

8.1.2 *Flat Specimen*—The flat specimen is made from the material of the second surface. The flat specimens are also treated as they would be in the application of interest. The dimensions of the contacting surface shall be large enough to accommodate the 25 mm diameter annulus without interfering with debris or lubricant escaping the contact. Flat specimens not thick enough to prevent bending should be supported in a rigid flat holder. Sheet metal specimens can be cut to fit into a rigid sheet holder. These specimens shall be flat across the entire surface of the specimen. Visual examination of the specimens after a test will confirm flatness of specimens and that uniform contact was made. If the visual examination indicates significant issues with the contact, then the result should be discarded and repeated.

8.1.3 *Surface Finish*—The surfaces should be representative of the application of interest. An isotropic surface finish (lapped) is preferred for the annular specimen contact surface.

9. Preparation of Apparatus

9.1 *Setting Nominal Contact Pressure*—The nominal contact pressure (σ) in this test is the contact force (F) divided by the apparent area of contact (A).

$$\sigma = F/A, \text{ where } A = \pi^*(\text{Radius}_{outer}^2 - \text{Radius}_{inner}^2) \quad (4)$$

The nominal contact pressure should be set based on the materials being tested and to enable discrimination between variables being evaluated while maintaining relevance to the

[3] See Schey, J. A., *Tribology in Metalworking: Friction, Lubrication and Wear*, ASM International, Metals Park, OH, 1983, pp. 211-213 and Schey, J. A., *A Critical Review of the Applicability of Tribotesters to Sheet Metalworking*, Society of Automotive Engineers, Inc., SAE 970714, 1997, pp. 114-115.

[4] *ACS Reagent Chemicals, Specifications and Procedures for Reagents and Standard-Grade Reference Materials*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

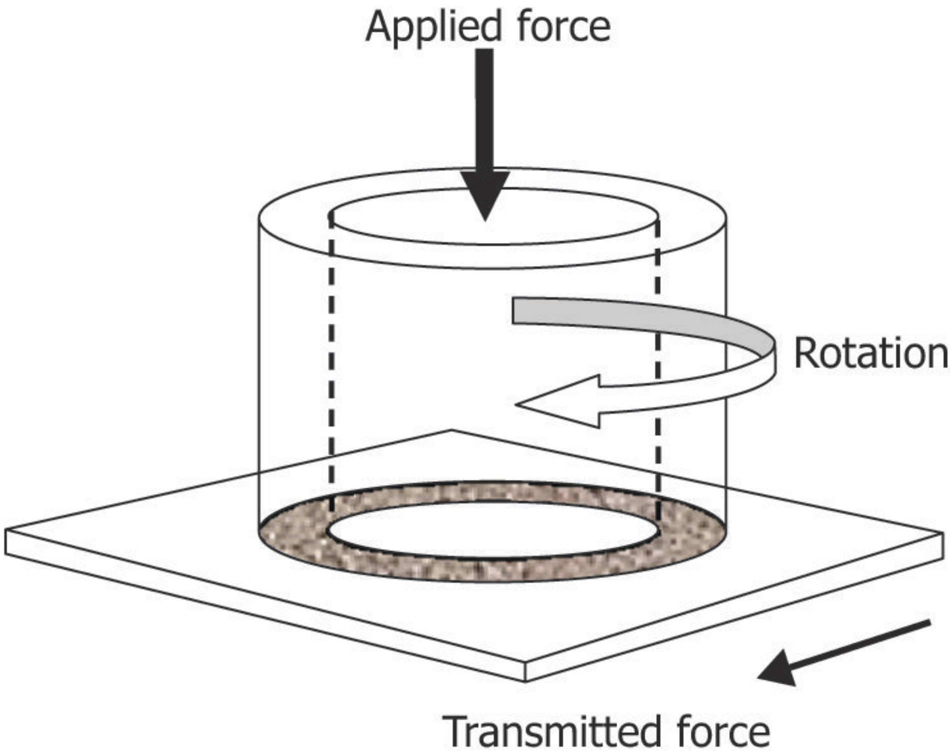

FIG. 3 Schematic of TCT Setup

application. A pressure of 55 MPa is commonly used for lubricated steel-on-steel tests and 34 MPa for nonlubricated steel-on-steel tests. The actual pressure used in tests shall always be reported. Table 1 lists the forces required to set the interface pressure based on the apparent contact area (25 mm OD hollow cylinder with a 3 mm wall thickness).

TABLE 1 Pressure Used in Tests

Interface Pressure		Normal Force	
MPa	psi	kN	lb
6.9	1000	1.55	349
13.8	2000	3.06	687
20.7	3000	4.59	1031
27.6	4000	6.11	1374
34.5	5000	7.64	1718
41.4	6000	9.17	2062
48.3	7000	10.70	2405
55.2	8000	12.23	2749
62.1	9000	13.76	3093
68.9	10 000	15.28	3436
75.8	11 000	16.81	3780
82.7	12 000	18.34	4123
89.6	13 000	19.87	4467
96.5	14 000	21.40	4811
103.4	15 000	22.93	5154
110.3	16 000	24.46	5498
117.2	17 000	25.98	5841
124.1	18 000	27.51	6185
131.0	19 000	29.04	6529
137.9	20 000	30.57	6872
144.8	21 000	32.10	7216
151.7	22 000	33.63	7559
158.6	23 000	35.15	7903
165.5	24 000	36.68	8247
172.4	25 000	38.21	8590
179.3	26 000	39.74	8934
186.2	27 000	41.27	9278
193.1	28 000	42.80	9621
199.9	29 000	44.33	9965
206.8	30 000	45.85	10 308
220.6	32 000	48.77	10 965

9.2 *Setting the Speed*—The rotational speed is set using an accurate stopwatch or within the data acquisition system. Tests should be run at 10 r ⁄min or 0.012 m ⁄s at the radius of gyration r/min. The rotational speed may be varied if appropriate for a particular project and reported. The approach speed of the two surfaces before contact should be set so that the surfaces come together smoothly. When testing very soft materials, including polymeric materials or films and high-viscosity lubricants, full nominal contact pressure may not be achieved for several seconds. For harder materials, such as metals, full nominal contact pressure is reached between 1.5 s to 2.0 s.

9.3 *Setting the Maximum Duration*—The duration of the test should be set so that the longest surviving condition expected (combination of material couple, surface treatment, coating, or lubricant (if any)) fails because of adhesive wear within that time if using 11.1.13.1. If using 11.1.13.2, all tests end after a predetermined time.

10. Calibration and Standardization

10.1 The force transducers are calibrated according to the manufacturer's recommendations. Additionally, a standard test condition should be run periodically to confirm TCT function. The effects of storage on material for the standard test condition specimens should be considered. The speed is set using a traceable timer.

11. Procedure

11.1 *Test Sequence:*

11.1.1 Use safety equipment and procedures recommended by the equipment manufacturer and on the safety data sheets (SDSes) for all chemical products being used for the cleaning and testing.

11.1.2 Warm up equipment before setting the speed and pressure. Follow procedure(s) to ensure proper alignment of specimens as recommended by the equipment manufacturer.

11.1.3 A minimum of three replicates are run for each condition.

11.1.4 Visually inspect specimens for flatness and the absence of nicks, scratches, and other obvious surface defects. For flat sheet metal specimens, remove excessive burrs if present.

11.1.5 If other cleaning procedures are not specified, use the following protocol. Wearing solvent-resistant gloves, clean the test specimens with the cleaning solvent appropriate for the residues being removed. Odorless mineral spirits are commonly used for removal of oily materials. A final wipe or rinse of the specimens with cleaning solvent using a lint-free laboratory tissue is recommended. A volatile solvent, heptane, for example, is most often used. If using a wipe, repeat the cleaning procedure until no dark residue appears on the tissue. (**Warning—**Use appropriate safety equipment and procedures.)

11.1.6 If a liquid lubricant is to be tested, it should be mixed to homogeneous appearance without inducing significant aeration into the lubricant sample before sampling for testing. If testing a grease or coating, a smooth, uniform, bubble-free layer should be applied to the surface of the flat specimen.

11.1.7 Special lubricant application methods or surface treatments, appropriate for the project, may be carried out if specified. Record the time between specimen surface preparation and when the testing is carried out. This time is a parameter that could influence test results.

11.1.8 Specimens are loaded into the TCT as appropriate for the instrument being used. The annular specimen contact surface may be cleaned using a lint-free wipe and volatile nonpolar solvent, such as heptane, after placing in the fixture to remove any contamination introduced during handling.

11.1.9 If testing material couples with liquid lubricants, an excess amount of lubricant (approximately 0.3 mL) is applied to the flat specimen at room temperature immediately before engaging the specimens unless other coating procedures are specified for the system.

11.1.10 Keep the time between liquid lubricant application and contact between the surfaces as consistent as practical. Lubricants may contain surface reactive or volatile ingredients or both. Record the time between lubricant application and test initiation if not tested immediately after application.

11.1.11 The rotating specimen is brought into contact with the stationary specimen under the normal load planned for the test (dynamic tests). Alternatively, rotation may be initiated after the desired normal load has been attained (quasistatic tests).

11.1.12 Two separate data channels, one for normal force and one for torque, are monitored and recorded.

11.1.13 If the test duration was not predetermined, nor other failure criteria used for automatic test termination, stop the test manually after lubricant film breakdown based on:

11.1.13.1 A rapid increase in friction or transmitted torque and

11.1.13.2 CFT or transmitted torque increasing to a predetermined level set based on experience.

NOTE 2—It is suggested that for a tool steel on ferrous metal lower specimen, the CFT for the film breakdown should be set to approximately 0.20.

11.1.14 The annulus and flat specimens should be examined after the test to verify adhesive failure and the criterion used to decide when it occurred. Examination may be carried out with the naked eye. Adhesion takes the form of material raised up from a surface or transferred to the opposing sample. Figs. 4-9 are optical microscope views of sections of annular specimens. Fig. 4, Fig. 6, and Fig. 8 are lapped D02 tool steel surfaces before testing. Fig. 5, Fig. 7, and Fig. 9 are after testing. Fig. 5, 304 stainless steel sheet test, shows heavy adhesion near the outer edge of the specimen. Fig. 7, copper sheet test, shows light adhesion near the outer and inner edges of the specimens, and Fig. 9, hot dipped galvanized sheet test, shows no adhesion. Tests were run at 48 MPa using a 93 mm^2/s at 40 °C mineral-oil-based lubricant containing synthetic ester and chlorinated paraffin. The contact surfaces shown are 3 mm thickness.

12. Report

12.1 The following data should be included in the test report if available and applicable to the project:

12.1.1 Pressure, MPa.