ASTM

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Standard Guide for
Determining Synergism Between Wear and Corrosion[1]

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1. Scope

1.1 This guide provides a means for computing the increased wear loss rate attributed to synergism or interaction that may occur in a system when both wear and corrosion processes coexist. The guide applies to systems in liquid solutions or slurries and does not include processes in a gas/solid system.

1.2 This guide applies to metallic materials and can be used in a generic sense with a number of wear/corrosion tests. It is not restricted to use with approved ASTM test methods.

1.3 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*
G 3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing[2]
G 5 Reference Test Method for Making Potentiostatic and Potentiodynamic Anodic Polarization Measurements[2]
G 15 Terminology Relating to Corrosion and Corrosion Testing[2]
G 40 Terminology Relating to Wear and Erosion[2]
G 59 Practice for Conducting Potentiodynamic Polarization Resistance Measurements[2]
G 102 Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements[2]

3. Terminology

3.1 *Definitions*—For general definitions relating to corrosion see Terminology G 15. For definitions relating to wear see Terminology G 40.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cathodic protection current density, i_{cp}*—The electrical current density needed during the wear/corrosion experiment to maintain the specimen at a potential which is 1 volt cathodic to the open circuit potential.

3.2.2 *corrosion current density, i_{cor}*—The corrosion current density measured by electrochemical techniques, as described in Practice G 102.

3.2.3 *electrochemical corrosion rate, C*—The electrochemical corrosion rate as determined by Practice G 59 and converted to a penetration rate in accordance with Practice G 102. This penetration rate is equivalent to the volume loss rate per area. The term C_w is the electrochemical corrosion rate during the corrosive wear process, and the term C_0 designates the electrochemical corrosion rate when no mechanical wear is allowed to take place.

3.2.4 *mechanical wear rate, W_0*—The rate of material loss from a specimen when the electrochemical corrosion rate has been eliminated by cathodic protection during the wear test.

3.2.5 *total material loss rate, T*—The rate of material loss from a specimen exposed to the specified conditions, including contributions from mechanical wear, corrosion, and interactions between these two.

3.2.6 *wear/corrosion synergism, S*—The rate of material loss resulting from the interaction of wear and corrosion processes, given by T minus the sum of W_0 and C_0. The component S' is the increase of mechanical wear rate due to corrosion, and S'' is the increase of the electrochemical corrosion rate due to mechanical wear.

4. Summary of Guide

4.1 A wear test is carried out under the test conditions of interest and T is measured.

4.2 Additional experiments are conducted to isolate the mechanical and corrosion components of the corrosive wear process. These are as follows:

4.2.1 A repeat of the experiment in 4.1 with measurement of C_w,

4.2.2 A test identical to the initial experiment in 4.1, except that cathodic protection is used to obtain W_0, and

4.2.3 Measurement of C_0, the corrosion rate in the absence of mechanical wear.

4.3 S, S' and S'' are calculated from the values measured in the experiments described in 4.1 and 4.2.

5. Significance and Use

5.1 Wear and corrosion can involve a number of mechanical and chemical processes. The combined action of these processes can result in significant mutual interaction beyond the individual contributions of mechanical wear and corrosion

(1-3).[3] This interaction among abrasion, rubbing, impact and corrosion can significantly increase total material losses in aqueous environments, thus producing a synergistic effect. Reduction of either the corrosion or the wear component of material loss may significantly reduce the total material loss. A practical example may be a stainless steel that has excellent corrosion resistance in the absence of mechanical abrasion, but readily wears and corrodes when abrasive particles remove its corrosion-resistant passive film. Quantification of wear/corrosion synergism can help guide the user to the best means of lowering overall material loss. The procedures outlined in this guide cannot be used for systems in which any corrosion products such as oxides are left on the surface after a test, resulting in a possible weight gain.

6. Procedures

6.1 A wear test where corrosion is a possible factor is performed after the specimen has been cleaned and prepared to remove foreign matter from its surface. Volume loss rates per unit area are then calculated, and the results tabulated. The value of T is obtained from these measurements. Examples of wear tests involving corrosion are detailed in papers contained in the list of references. These examples include a slurry wear test (1-3), a slurry jet impingement test (4), and a rotating cylinder-anvil apparatus (5).

6.2 A wear test described in 6.1 is repeated, except that the wear specimen is used as a working electrode in a typical 3 electrode system. The other two electrodes are a standard reference electrode and a counter electrode as described in Practices G 3 and G 59, and Reference Test Method G 5. This test is for electrochemical measurements only, and no mass or volume losses are measured because they could be affected by the electrical current that is passed through the specimen of interest during the experiments. Two measurements are made, one to measure the polarization resistance as in Practice G 59, and one to generate a potentiodynamic polarization curve as in Test Method G 5. The open circuit corrosion potential, E_{cor}, the polarization resistance, R_p, and Tafel constants, β_a and β_c, are tabulated. The exception to Test Method G 5 is that the apparatus, cell geometry, and solutions or slurries used are defined by the particular wear test being conducted, and are not restricted to the electrochemical cell or electrolyte described in Test Method G 5. The potentiodynamic method rather than the potentiostatic method is recommended. R_p, β_a and β_c are used to calculate the electrochemical corrosion current density, i_{cor} as described in Practice G 59. The value for i_{cor} is then converted to a penetration rate in accordance to Practice G 102. This penetration rate is equivalent to the material loss rate, C_w.

6.3 A wear test similar to that conducted in 6.2 is run again except that the wear specimen is polarized 1 volt cathodic with respect to E_{cor} so that no corrosion takes place. The mass loss of the specimen is measured during the cathodic protection period by weighing it before and after the test. W_0 is then calculated by dividing the mass loss by the specimen density and exposed surface area. The current density i_{cp} is also

recorded. Caution must be used when using this technique because some metals or alloys may be affected by hydrogen embrittlement as a result of hydrogen that may be generated during this test. If hydrogen evolution is too great, then there is always a possibility that the hydrodynamics of the system could be affected. However, the results of research (1-5) have shown these effects to be minimal for the ferrous alloys studied to date.

6.4 A corrosion test similar to that conducted in 6.2 is run again except no mechanical wear is allowed to act on the specimen surface. The penetration rate, which is equivalent to C_0, is obtained as in 6.2, using polarization resistance and potentiodynamic polarization scans to obtain R_p, β_a, β_b and i_{cor}.

6.5 T, W_0, C_w, and C_0 are all reported in units of volume loss per exposed area per unit time. The synergism between wear and corrosion is calculated according to (Eq 1), (Eq 2), and (Eq 3).

6.6 Caution must be used to make sure that the surface area exposed to corrosion is the same as that exposed to mechanical wear. Coating of the portions of the specimen with a non-conductor to mask off areas to prevent corrosion is an effective means of doing this.

7. Calculation of Wear/Corrosion Synergism

7.1 The total material loss, T, is related to the synergistic component, S, that part of the total damage that results from the interaction of corrosion and wear processes, by the following equation

$$T = W_0 + C_0 + S \tag{1}$$

7.1.1 (Eq 1) implies that corrosion can affect mechanical wear and mechanical wear can affect corrosion.

7.2 Under conditions of corrosive wear, C_w can be measured by electrochemical means. C_w is usually higher than C_0 because of mechanical wear interaction. (Eq 1) can be rewritten

$$T = W_0 + C_w + S' \tag{2}$$

where $S' =$ increase in the mechanical wear losses due to corrosion. Increases in the corrosion rate due to wear are included in C_w.

7.3 From (Eq 1) and (Eq 2) it can be shown that the change of the electrochemical corrosion rate due to mechanical wear, $\{C_w - C_0\}$, is equal to the difference between S and S'. This difference is designated S'' as follows:

$$S'' = S - S' = C_w - C_0 \tag{3}$$

7.4 As it should be, the total synergism is the sum of the increase of mechanical wear due to corrosion, S', and the increase of corrosion due to mechanical wear, S'',

$$S = S' + S'' \tag{4}$$

7.5 The equations in Section 7 can be summarized by the following:
By definition:

	$T = W_0 + C_0 + S$	(I)
and	$S = S' + S''$	(II)
hence,	$T = W_0 + S' + C_0 + S''$	(III)
also,	$C_w = C_0 + S''$	(IV)
hence,	$T = W_0 + S' + C_w$	(V)

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[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

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By testing:

From 6.1, one obtains T.
From 6.2, one obtains C_w.
From 6.3, one obtains W_0.
From 6.4, one obtains C_0.

By calculation, using test results and definitions:

From (V),	$S' = T - W_0 - C_w$	(VI)
From (IV),	$S'' = C_w - C_0$	(VII)
From (II),	$S = S' + S''$	(VIII)

From the above the following dimensionless factors can be defined to describe the degree of synergism:

$T/(T - S)$	("Total Synergism Factor")	(IX)
C_w/C_o	("Corrosion Augmentation Factor")	(X)
$(W_o + S')/W_o$	("Wear Augmentation Factor")	(XI)

8. Report [4]

8.1 The report should include the test method used and the test conditions.

8.2 A sample of a Test Data Recording form is shown in Fig. 1.

8.3 A sample of a Test Summary form for several tests is shown in Fig. 2.

9. Keywords

9.1 aqueous; corrosion; electrochemical; erosion-corrosion; slurries; solutions; synergism; wear

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[4] See appendixes for example of parameter calculations and test data.

TEST	—Test Number :						
DATE	—Date :						
ENVIRONMENT	—Description :						
SPECIMEN Identification:	Material property		Wear Specimen		Counterface Material		
	—Density, g/cm^3						
	—Specimen area, mm^2						
	—Equivalent weight						
WEAR TESTS	Initial wt, g	Final wt, g	Wt loss, g	Time, h	Material loss, $\frac{mm^3}{mm^2}$	Material loss rate, $\frac{mm^3}{mm^2-yr}$	Material loss rate symbol
Corrosive Wear Test							T
Cathodic Protection Test							W_0
ELECTRO-CHEMICAL TESTS	E_{cor}, mV vs SCE	i_{cor}, µA/cm^2	R_p, ohms-cm^2	β_a, $\frac{mV}{decade}$	β_c, $\frac{mV}{decade}$	Material loss rate, $\frac{mm^3}{mm^2-yr}$	Material loss rate symbol
Electrochemical test with wear							C_w
Electrochemical test without wear							C_o

FIG. 1 Test Data Recording Form