

A Comparison of Galling Test Methods by the Specific Energy Approach

Extended Abstract for: Presentation made at the
25th meeting of The IRG on Wear of Engineering Materials
Uppsala, Sweden – June 14, 2004

S. J. Shaffer – Battelle Memorial Institute

Introduction

Background: The Galling Phenomenon - Galling is a severe mode of wear in which significant surface deformation results. Galling can occur in sliding contact under conditions of inadequate liquid lubrication, or when the contact stresses are sufficient to penetrate any boundary lubrication films, including natural oxides or contaminant films on unlubricated surfaces. While there is no current official definition of galling, it is readily described in terms of its physical manifestation, in which severe disruption of a material's surface occurs, resulting in macroscopic damage, generally significant plastic deformation via subsurface tensile tearing, and often material transfer. Galling can be likened to “machining with a very dull tool.” The samples shown in Figure 1 exhibit a manifestation of galling in which the displaced material has smeared over the surface due to reciprocating motion of the test. Figure 2 shows the result of subsurface tensile tearing in a single stroke flat-on-flat test.

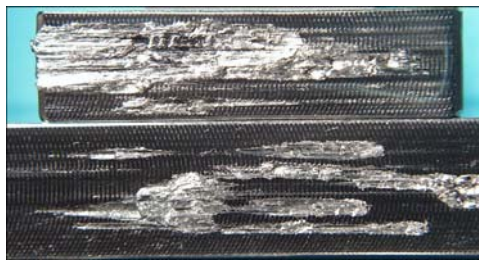


Figure 1 – Galled AISI 316 stainless steel samples after 4 reciprocating cycles of sliding under a contact stress of 70 Mpa. Width of upper sample is 0.6 cm.



Figure 2 – Galled AISI 1020 carbon steel samples after a single sliding stroke under a contact stress of 70 Mpa. Width of sample is 1.27 cm.

While galling is often associated with adhesive wear, “welding” is not a necessary condition. Formation, growth and deformation of pileups or prows trapped in the contact zone can also result in galling without any cold welding or adhesion. It is only sufficient that surface shear stresses are transmitted into the subsurface, and at some point the

resolved tensile stress exceeds the local material tensile strength. The trapping of adhesive junctions or prows under the interface makes larger, conformal or flat contacts more prone to galling than small or hemispherical geometry contacts. This is one reason for discrepancies seen in the “threshold” reported in different galling tests of the same material.

Galling Tests - There are two primary reasons galling tests are conducted:

(1) To determine the suitability of a selected material for a given application. For example: A material or coating may be required for a new “lubricant free” design which must function in a dusty or sandy environment, where sand attracted by a liquid lubricant will result in failure of the mechanism. Or, in a high temperature and pressure steam or water environment where lubricants would be washed away and thus clean metal on metal surfaces are in contact.

(2) To benchmark the successful development of new galling resistant materials. For example: Development of cobalt-free hardfacings to replace traditional cobalt-based hardfacings.

Factors Influencing Galling - Many of the factors influencing galling can be related to temperature, energy input, and removal of protective/contaminant layers including:

- Surface Chemistry - Presence of adsorbed species, surface oxides and presence of debris - Breakdown or removal of surface protective layers is important for galling.
- Contact Configuration - Contact geometry, contact area, surface roughness and lay of the roughness can lead to local very high contact stresses and specific energy input.
- Temperature – Load or stress, speed, sliding distance, ambient temperature and duty cycle all contribute to increased temperature, which can lower the yield strength, and/or desorb surface films, both of which promote galling.
- Sliding Distance - Thermal and mechanical input removes films, grows junctions, and raises temperature, which promotes galling.

Finally, there is a contribution of “probability” in galling. Samples may slide without galling for 50 cycles, but galling might occur on the 51st cycle.

Galling Tests - Because the occurrence of galling is a probabilistic phenomenon, and because galling is both strongly dependent on the contact stress, geometry and environment, generic galling tests are often limited in their usefulness, even for simple ranking of materials. As such, specific tests have been developed for various applications, and a number of these have been presented in the literature. Figure 3 shows several test geometries that have been used in galling tests.

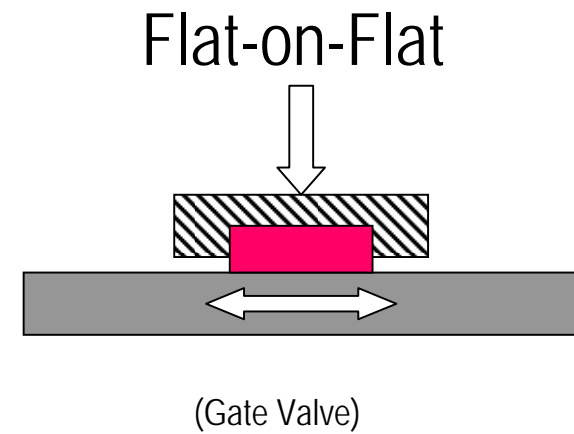
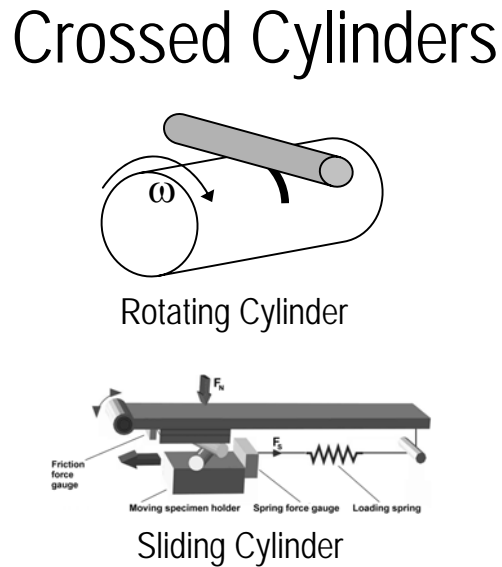
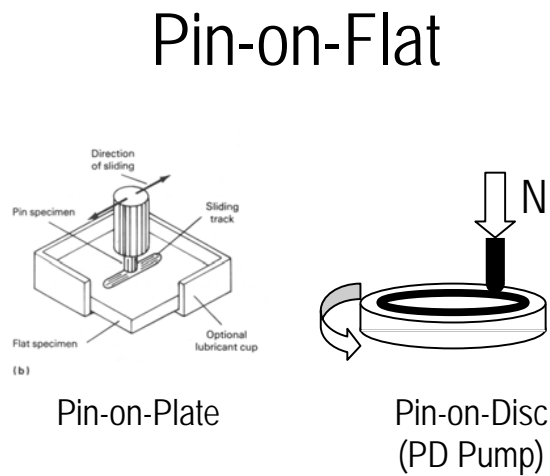
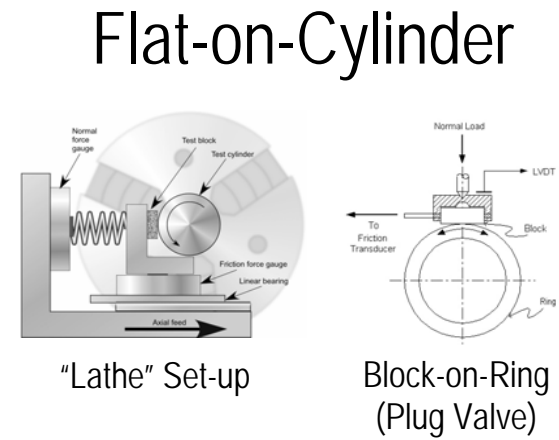
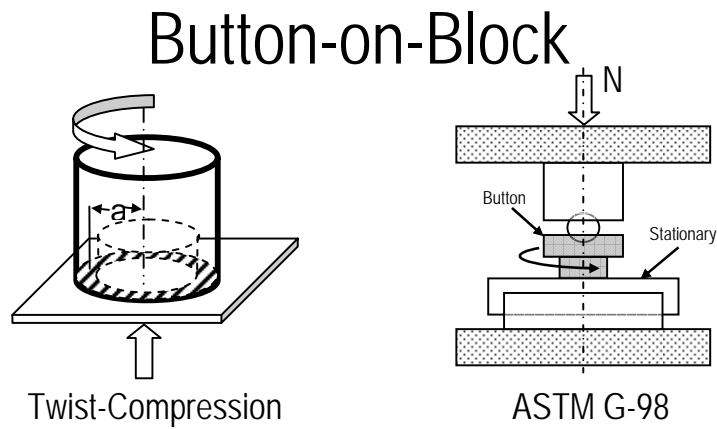


Figure 3. Examples of galling test geometries

Correlation Between Galling Test Results – Although the relative ranking of materials is generally consistent in any given test, the occurrence of galling, or the “galling threshold” may differ from test to test. As such, a material or material combination might be being characterized as non-galling due to its performance in a particular test, whereas it might gall in another test or when used in the actual application.

Assuming that sample surface preparation and cleaning may have been identical, the primary reason for this is believed to lie in the energy input during the test. Since energy, in the form of thermal input, can lead to desorption of surface films, a breakdown of lubricant protective films, and a degradation in mechanical properties of the base materials, it is likely that the differences observed in galling behavior between different tests may be related to the energy input between the test surfaces in sliding contact. As such, to separate the material contributions of galling from those that are test rig and contact geometry dependent, it would be insightful to compare a given material in different tests under conditions of the same energy input.

Comparison of Galling Tests on an Energy Basis – For several of the test geometries and known test rig parameters (e.g. load, speed, sliding distance) shown in Figure 3, Table 1 shows a comparison based on both work (energy) and specific energy input during a single “stroke” or cycle. As a result of contributions from sample contact patch size, load, stroke length and sliding speed, an order of magnitude differences is seen in these comparisons of work or specific energy.

With the appropriate adjustments made to the various test parameters mentioned, it is possible to conduct these tests under conditions of roughly equivalent energy per stroke or equivalent specific energy per stroke, as seen in Tables 2 and 3.

Call for Research Collaborators – Interested members of the IRG are invited to collaborate in the running of tests under different geometries to investigate the possibility of developing a method of comparing galling tests using one of these methods. It may also be that speed be incorporated, and therefore power or specific power would be the basis for comparison. Please contact Steve Shaffer at shaffers@battelle.org if you are interested in collaborating this area.

Table 1 – Comparison of Galling Test Methods

Test Geometry	Flat-on-flat	Annular ring on plate	Button-on-block (G98)	Flat-on-cylinder	Pin-on-disk	Block-on-ring	Crossed Cylinders
Rig Operator	Shaffer	Dalton	Hummel	Hummel	Zimmer	Gosset	Hogmark
application	6" gate valve	sheet forming	general research	medical instruments	PD pump	plug valve	research - DLC on 52100 steel
footprint shape	rectangle	annular ring	circular spot	line - initially Hertzian	circular spot - initially	line - initially Hertzian	ellipse - initially Hertzian
motion	linear reciprocating	concentric rotation of ring	concentric rotation of button	rotation of cylinder about axis	rotation of flat disc about axis	+/- 25 deg. reciprocating rotation of ring	linear (reciprocating)
load (N)	11121	22241	8896	1112	200	44	1112
area (cm ²)	1.613	2.217	1.267	0.040	0.211	0.032	0.010
Stress (MPa)	68.9	100.3	70.2	277.1	9.5	13.8	1112.1
"stroke" length (cm)	7.62	6.98	1.99	6.00	18.95	3.05	7.00
velocity (cm/min)	41	70	20	66	2032	457	600
stroke duration (sec)	11.25	6	6	5.45	0.56	0.4	0.7
Duty Cycle	0.33	1	1	0.004	0.028	0.017	0.006
Work in one stroke = load * stroke length (J)	847	1553	177	67	38	1	78
"Specific Energy" per stroke = Work / area (J/cm²)	525	701	140	1663	180	42	7784

Table 2 – Comparison on the Basis of Equivalent Energy

Test Geometry	Flat-on-flat	Annular ring on plate	Button-on-block (G98)	Flat-on-cylinder	Pin-on-disk	Block-on-ring	Crossed Cylinders
Rig Operator	Shaffer	Dalton	Hummel	Hummel	Zimmer	Gosset	Hogmark
load (N)	4000	4300	8896	1112	200	890	1500
"stroke" length (cm)	7.5	7	3.4	27	150	34	20
area (cm ²)	1.613	2.217	1.267	0.040	0.211	0.032	0.010
Energy in one stroke = load * stroke length (J)	300	301	302	300	300	302	300
"Specific Energy" per stroke = Work / area (J/cm ²)	186	136	239	7482	1421	9377	30000

Table 3 – Comparison on the Basis of Equivalent Specific Energy

Test Geometry	Flat-on-flat	Annular ring on plate	Button-on-block (G98)	Flat-on-cylinder	Pin-on-disk	Block-on-ring	Crossed Cylinders
load (N)	21200	31800	63610	672	440	445	334
area (cm ²)	1.61	2.22	1.27	0.04	0.21	0.03	0.01
"stroke" length (cm)	7.62	6.98	1.99	6.00	48	7.3	3.0
Work in one stroke = load * stroke length (J)	1615	2220	1269	40	211	32	10
"Specific Energy" per stroke = Work / area (J/cm ²)	1002	1002	1002	1004	1000	1007	1002