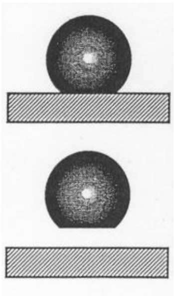
Guidance - Notes on Test Specimens

Friction and Wear

What could be simpler than to design an experiment in which we rub a couple of bits of material together and make a few measurements? The problem is that with tribology we are not concerned with single "properties" of materials, but how those materials behave when placed in complex systems. Friction and wear are not intrinsic material properties but are properties of the system in which the materials operate. It follows that the properties measured in an experiment using a test machine are also a system properties. Hence the data generated from any properly calibrated test machine has to be valid, but only for the performance of the materials in that machine.

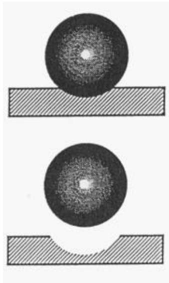
Hard on Soft or Soft on Hard

One issue we have to address when designing a test is which way round, in terms of relative hardness, to have the specimen pair. Traditionally, many idealized wear tests have involved running a soft pin or ball on a hard disc or plate. Under these conditions, the wear occurs on the softer material, sometimes accompanied by the generation of a transfer film on the harder material. If a transfer film is created, the ball or pin sample ends up running on a film of its own material, hence like on like.



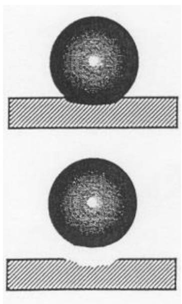
Measurement of material lost from the softer pin or ball is relatively easy. It should however be remembered that if material has been transferred to the disc or plate, its mass may increase.

If the specimen pairs are reversed, with a harder pin or ball running on a softer disc or plate, we generate a different mechanism, depending on the relative hardness, the contact pressure and contact shape. What happens to the disc or plate specimen depends on the nature of the material. With metallic specimens, plastic deformation of the surface and work hardening may take place thus changing the nature of the material. With coated surfaces, repeated passes by a hardened pin or ball may give rise to adhesion-de-lamination and subsequent failure of the coating.



If we define wear exclusively as the removal of material, it will be apparent that if the scar generated on the disc or plate specimen involves plastic deformation (material is redistributed but not removed), then it cannot be considered in the true sense as a “wear” scar. With this contact configuration, the processes involved may be more analogous to forming or machining processes. In the case of forming, we would anticipate plastic deformation, and in the case of machining, removal of material by cutting or ploughing action. The forming process may not result in any material loss from the disc or plate specimen, which is not the case with the bulk material removal in a ploughing or cutting action. We would expect the apparent friction force to be higher in this case than in the former case, because of the forces involved in pushing the material out of the way. Indeed, if you run a hard ball on a rubber sheet, a “bow-wave” effect can be observed as the sheet material is deformed in the direction of motion.

Now, in real machines, we frequently find contacting materials of similar hardness, with the result that wear is shared between the two contacting surfaces. The only solution here is to measure the wear on both surfaces, not forgetting that, if the materials are different, the wear rate will still be dependent on which material is used for the pin or ball and which is used for the disc or plate. This is because the energy inputs are different for the two specimens.



The key thing to note with these three examples is that they represent three different friction and wear systems. But this is not the end of the story.

Sharing of Wear and Overlap Parameter

If we run tests with a soft pin on a hard disc, we tend to confine the wear to the soft pin. However, when we have materials of similar hardness, we need to consider how the wear is shared between the contacting surfaces.

If, for example, we have a 10 mm diameter pin running on a 100 mm circumference disc track, then in one revolution, a point on the pin experiences 100 mm of sliding. However, a similar point on the disc sees only a single pass of the pin, hence a sliding distance on just 10 mm. Double the track circumference and the point on the pin sees 200 mm sliding per revolution whereas the point on the disc still only sees 10 mm.

So, the basic problem is that at anything other than very small track diameters, all the sliding effectively takes place on the pin surface. Now, as previously stated, this probably does not matter if we have a soft pin on a hard disc, but it certainly does matter if we have materials of similar hardness, as changing the track diameter has a

direct impact on how the sliding distance, hence wear, is shared between the two surfaces. It also means that running repeat tests at different track diameters at the same surface speed on the same disc will generate different wear rates.

By contrast, with the thrust washer arrangement, the sliding distance for a point on either sample has to be the same. This probably makes it a better arrangement for testing materials of similar hardness, unless, of course, we wish deliberately to confine the majority of wear to one surface.

The "overlap parameter" (Czichos) is defined as the ratio of sliding distance for "body" divided by sliding distance for "counter body". For the thrust washer this is 1, for fretting tests it is close to 1, but for pin on disc tests it is variable, but is typically less than 0.05.

The overlap parameter also applies for reciprocating tests, but here there is not the temptation to use the equivalent of different pin on disc track diameters, as one sensibly keeps the stroke the same.

Sharing of Wear and Ring-Liner Model

In a fired engine, we tend to produce about the same amount of wear on the ring as on the liner. In the reciprocating bench test, we end up with much more wear on the liner specimen than on the ring, which is to be expected.

Consider a ring providing a contact length of, say, 3 mm, an engine with a stroke of 100 mm and a bench test with a stroke of 15 mm. In 10,000 cycles, the sliding distance for the ring in the engine is:

$$2 \times 10{,}000 \times 100 \text{ mm} \quad = \quad 2{,}000 \text{ m}$$

The sliding distance for a given point on the liner is:

$$2 \times 10{,}000 \times 3 \text{ mm} \quad = \quad 60 \text{ m}$$

Ratio of sliding distance ring/liner = 33.3

In the bench test, we get the following:

Sliding distance for the ring:

$$2 \times 10{,}000 \times 15 \text{ mm} \quad = \quad 300 \text{ m}$$

Sliding distance for a given point on the liner:

$$2 \times 10{,}000 \times 3 \text{ mm} \quad = \quad 60 \text{ m}$$

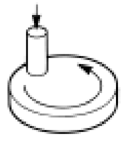
Ratio of sliding distance ring/liner = 5

So, as regards a point on the liner, the number of passes and hence the sliding distance remains the same for the engine and the bench test (correct model), however, the sliding distance for the ring sample in the bench test is only 15 % of that in the engine. Ignoring the issue of lubricant entrainment, changes in the wear process, thermal diffusivity etc, we could perhaps conclude that the bench test understates the ring wear by 85 %.

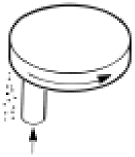
This is of course a scale effect. To get the model exactly right, we should scale the contact length correctly. Hence, if we run at 15 mm stroke modelling a contact length of 3 mm in engine with 100 mm stroke, we should use a ring specimen in the test machine of 0.45 mm contact length.

Which Way Up

If we run a pin on disc machine with the pin loaded onto the disc from above any wear debris generated will tend to accumulate on the surface.



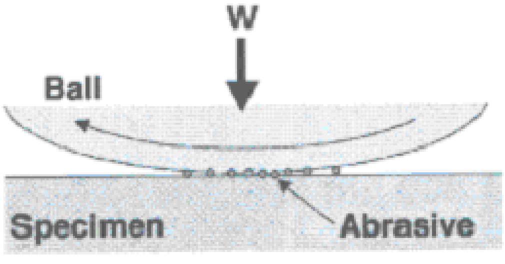
This will give different behaviour from exactly the same configuration turned upside down.



In this case, the debris may fall off the disc surface giving a different friction and wear performance compared with the previous case.

Entrained Debris

If the debris remains on the surface and can enter the contact, depending on the shape, size and relative hardness of the debris, there is the potential for at least two different types of wear mechanism.



The contact in this case is now quite definitely operating in what is classically referred to as "three body abrasion", with the wear debris acting as the third body. However, the term "three body abrasion" is perhaps somewhat confusing and it should perhaps be referred to as "third body abrasion" for clarity.

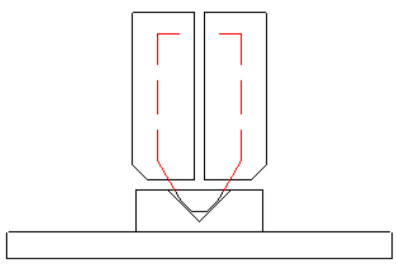
The first thing to note is that in third body abrasion, the fewer the particles in the contact the higher the load on each particle. Under high loads, a particle may become either permanently embedded in the softer specimen material or temporarily trapped within an asperity on one surface. Under these conditions, the particle will tend to be dragged without rolling across the counter face material and will produce "grooving wear", which is in effect "two body abrasion".

As more particles enter the contact, the load on each particle reduces to the point where the risk of a particle becoming embedded either permanently or temporarily is eliminated. Under these conditions, the particles may have sufficient freedom to allow them to roll. This will produce "polishing wear", which is genuine "three body abrasion".

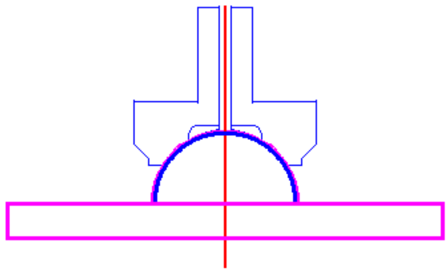
The interesting thing is that we would expect the friction force with polishing wear to be substantially less than with grooving wear, because in the former the rolling particles act like miniature rolling element bearings.

Specimen Pin Alignment

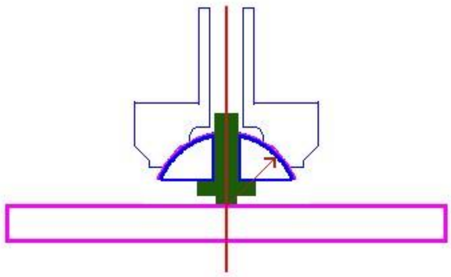
We need to be careful when running a hard pin on a soft disc or plate. With a ball-ended pin, alignment problems are removed but the test starts with high hertzian contact pressures resulting in plastic deformation and work hardening of the softer disc. If we are running with a flat-ended pin, we avoid the high contact pressure and work hardening issue but we have to pay particular attention to the alignment and particular attention to the edge of the pin, in both cases to avoid the pin "machining" a groove in the softer material. One way of improve alignment is to use a self-aligning "button" type specimen with a bullet shaped driver, such as:



Another form of self-aligning arrangement is to use a hemisphere for the pin:

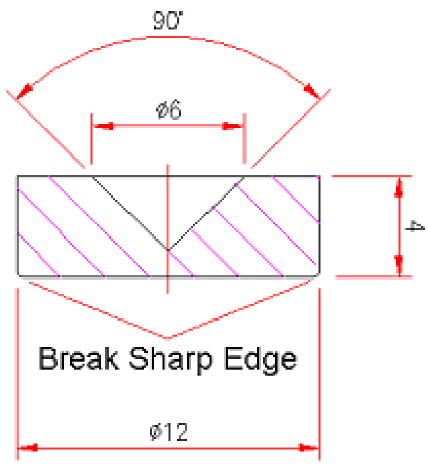


Or a spherical pin carrier:



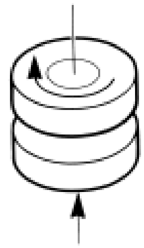
In both cases, the centre of the contact should be the centre for the spherical seat.

To avoid a "machining" edge, the edge around the circumference of the pin contact area should be "broken" in a systematic and re-producible way:

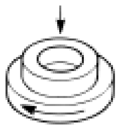


Thrust Washer Specimens

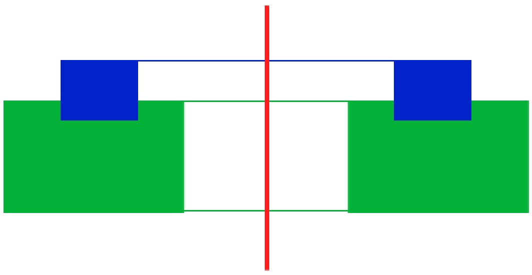
The thrust washer test configuration provides continuous contact on both test surfaces and thus avoids the sharp leading edge problems of the pin on disc or pin on plate configuration.



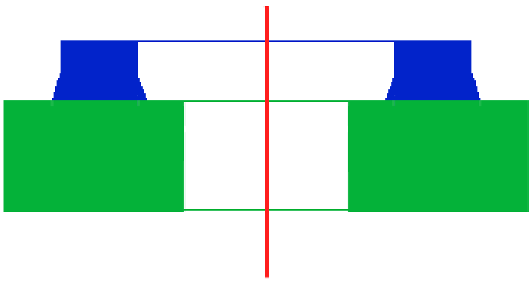
However, even with a continuous contact, edge effects must be considered, especially if one specimen has a smaller outer diameter and larger inner diameter than the other.



If the smaller outer diameter specimen (the upper specimen in the sketch) is harder than the larger diameter specimen, it will cut into surface of the latter and the frictional behaviour of the contact will be dominated by circumferential edge effects.

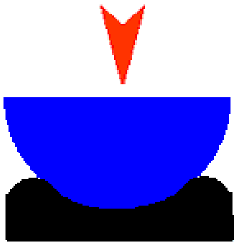


If the smaller upper specimen is softer that the larger diameter lower specimen, the edge effect is removed, but elastic deformation of the softer material may result in a change in apparent area of contact.

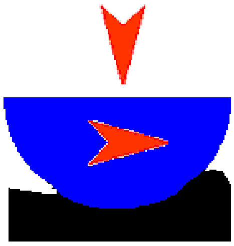


Rubber Samples

Testing or rubber or other elastomeric samples in contact with a hard surface presents a particular challenge.

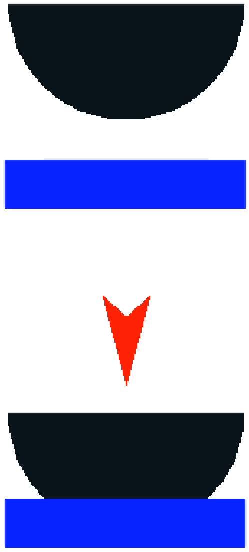


There are considerable problems with the hard ball on soft rubber flat test configuration, in both dry and lubricated sliding. The hard ball deforms the softer surface elastically and material relaxation occurs with time.



With relative sliding, a bow wave of material forms in the direction of sliding with a wake of recovering material left behind in the opposite direction. The vector of the resisting force is indeterminate and it is not exclusively generated by friction.

Our recommended solution (developed in collaboration with Dr Allen Roberts [formerly of MRPRA]) is to use the rubber sphere or hemisphere on hard flat test configuration.



In this configuration the rubber sample is self-locating and issues of specimen alignment, fluid entrainment (in lubricated tests) and material hysteresis effects are minimized. The resisting force vector is fully deterministic and is generated by friction.

Providing the load on the sphere is not too large and the sliding speed not too high, the mechanism of velocity accommodation between the rubber sphere and the hard flat probably involves Schallamach waves of detachment generated at the leading edge and travelling through the contact to the trailing edge.

The rubber flat on hard flat test configuration is a possible alternative to the rubber sphere or hemisphere on hard flat test configuration, but is not without problems. The edge conditions, where Schallamach waves initiate, are very different from the self-locating solution. The support length for the rubber "button" sample has a significant effect with the sample and its holder behaving like an elastic cantilever and generating gross stick-slip. The sample has a tendency to tilt when driven across the counter face, so the real area of contact may be less than anticipated.