WEAR PROPERTIES OF ELECTROLESS NICKEL

As was already pointed out, a primary reason for using electroless nickel is to protect substrates not only from corrosion, but also from wear. Wear is the gradual mechanical deterioration of contacting surfaces. One type, adhesive wear, results from the welding of the mating surfaces. As no actual surface is atomically smooth, it consists of asperities and depressions, i.e., hills and valleys. When two surfaces are brought together, the area of contact consists primarily of the tops of the asperities, and is therefore only a small fraction of the total area. A relatively light load applied to the two mating parts thus results in a large stress, i.e., the load divided by the contact area. The lateral movement of one,surface relative to the other can remove any oxide or other soils on the tops of the asperities. Thus, the conditions for welding, namely intimate contact between two clean surfaces exist. Welding may be increased when the metals of the contacting surfaces are similar and mutually soluble in each other. The lateral movement can shear the welds again. If the shear fracture does not occur at the original weld, material from one surface adheres to the other. The resulting weight loss is adhesive wear. It is also possible that the shear fracture takes place on both sides of the original weld producing a separate particle. Then both surfaces undergo adhesive wear. Such particles, as well as ones from other sources can abrade the surfaces, causing a second type, namely abrasive wear. Abrasive wear can be minimized by making the surface harder and smoother. Hardening of a surface and lubrication reduce adhesive wear. If strong bonds develop under stress over a large portion of the contacting area, the mating surfaces may gall or seize, resulting in gross damage. Selecting dissimilar mating materials helps to avoid welding.

Adhesive and abrasive wear are related, though not directly, to the hardness of a surface, which is an indication of how much the tops of the asperities deform plastically. The greater the hardness, the less deformation, and consequently, there is less intimate contact and less welding and friction. Hard surfaces are also less likely to have the shear fracture occur at the original weld, resulting in less wear. Polishing the contacting surfaces also reduces wear because the contact area is larger and the stress that produces the intimate contact leading to welding is reduced.

Lubrication also reduces friction and wear by inhibiting the intimate contact. When hard particles, such as oxides, carbides, and diamonds are included in electroless nickel, they constitute the principal areas of contact. As these particles are less likely to weld, they reduce adhesive wear (18). However, if they are pulled out of the matrix they can cause abrasive wear. The inclusion of PTFE, which would tend to be smeared over the contacting surfaces, reduces friction by preventing the intimate contact that leads to welding and abrasion (56).

The abrasive wear properties of electroless nickel can be improved by heat treatment. However, such heat treatment may lower its corrosion resistance. In general, thin electroless nickel coatings are only effective under relatively mild wear conditions. Severe or sudden loading should be avoided. Good adhesion to the substrate is essential for satisfactory wear performance. A hard coating on a soft substrate such as aluminum is easily disrupted and penetrated by a hard, rough contacting surface. Therefore, a hard substrate provides better support for electroless nickel coatings.

Wear under working conditions is a very complex phenomenon. Among the many parameters that affect wear and make it difficult to control are surface hardness and finish; the microstructures and bulk properties of the mating materials; the contact area and shape; the type of motion, its velocity and duration; the temperature; the environment; the type of lubrication; and the coefficient of friction. The various laboratory tests can only provide indications of how parts will behave in service. Values of hardness and coefficients of friction can serve as a guide in selection of materials for a specific application. Trials under actual service conditions are still the only reliable indicators of how a part will wear.

The coefficients of friction of electroless nickel in the as-plated condition are generally higher than those of electroplated chromium (19). Some values of the friction coefficient of a 9 percent P electroless nickel alloy against three different mating materials, with and without lubrication, are shown in Table 4.5 (19). The coefficients of friction of pins coated with Ni-P or Ni-B deposits are compared in Table 4.6 against various plates of different metals. Friction coefficients for lubricated Ni-B coated pins are also presented. It is evident that under dry conditions the Ni-B deposits have higher coefficients of friction, especially against copper and bronze. It can also be seen from Table 4.6 that the coefficients of friction do not bear a direct relationship to the hardness of the plates. The coefficient of friction for electroless nickel against steel appears to be relatively independent of phosphorus content. The least wear of electroless nickel against quenched steel is obtained when the deposit contains between 8 and 12 percent P after heat treatment at 400 to 600° C (57).

Other wear test results are presented in Tables 4.7 and 4.8 (18). The wear data in Table 4.7 were obtained using a LFW-1 tester according to ASTM D2714-68. It compares the wear of a block against a rotating ring. The electroless nickel data in Table 4.8 were obtained with a Falex tester according to ASTM D2670-67. In this tester, a pin (journal) is rotated between two V-shaped blocks. The data in Tables 4.7 and 4.8 show a good correlation of hardness of the electroless nickel deposit to wear. The least wear resulted when the electroless nickel had been

Table 4.5
Friction Coefficients of Several Mating Surfaces (19)

Mating surfaces	Coefficients of friction	
	Unlubricated	Lubricated
Electroless nickel (EN) vs. steel	0.38	0.19-0.21
Cr vs. steel	0.19-0.23	0.12-0.13
Steel vs. steel	galling	0.2
EN vs. EN	0.45	0.25
Cr vs. Cr	0.43	0.26
EN vs. Cr	0.43	0.30

Table 4.6
Friction Coefficients of Electroless Nickel Against Different Metals (19)

	Plate properties		Coefficients of plated pin vs. plate		
			Ni-P (11)	Ni-B (13)	
Metal	Hardness, kg/mm^2	Finish, μm	dry	dry	lubricated
Steel*	960	2.6	0.32	0.44	0.12
Steel**	310	3.0	0.37	0.43	0.13
Gray iron	210	2.9	0.30	0.38	0.12
Hard Cr	960	1.2	0.38	0.36	0.10
Cu (plated)	105	2.7	0.33	0.70***	0.10
Bronze	200	1.0	0.26	0.65	0.09

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*Hardened 105WCr6 steel.
**Normalized 105WCr6 steel.
***After surface was abraded.

Table 4.7
LFW-1 Wear Test Results

Heat treatment		EN-plated ring vs. block			EN-plated block vs. ring		
°C	hr	HVN_{100}	Coefficient of friction	Weight loss, mg	HVN_{100}	Coefficient of friction	Weight loss, mg
As plated		523	0.09	102	585	0.13	9.0
260	1	743	0.09	50	724	0.13	8.8
260	10	1010	0.11	13	988	0.13	2.8
400	1	1060	0.11	1	1064	0.10	2.3
540	1	not tested			892	0.10	1.7

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*The hardness of the unplated steel block and ring were Rc 60 and 65, respectively. In the tests of the plated ring vs. block, the load was 284 kg and the ring rotated for 25,000 revolutions. In the plated block vs. ring test, the load was 68 kg and the ring rotated for 5000 revolutions. The lubricant was USP white oil. The rotational velocity of the ring was 72 rpm.

Table 4.8
Falex Test Data of Rotating Pins vs. V Blocks (18)*

EN deposit Heat treatment °C	hr	HV	Unplated pin W.L.*	Plated block W.L.	Plated pin W.L.	Unplated block W.L.
As plated		590	0.2	6.6	—	—
288	2	880	0.1	1.2	3.9	0.3
288	16	1050	0.1	1.2	3.7	0.7
400	1	1100	0.2	0.5	3.0	1.5
540	1	750	0.1	0.4	5.6	0.8
Chromium		1050	1.9	0.5	6.2	15.0

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*The unplated V blocks and pins had hardnesses of Rc 20 to 24 and 60, respectively. The loads were 94 kg applied for 1 hr and 182 kg applied for 40 min. The pin rotated at a speed of 290 rpm. The lubricant was white oil.

**Weight loss, mg.

heat treated to HV 850 to 1100, as obtained at 260 to 290° C in 2 to 10 hours, or at 400° C in less than 1 hour. A minimum hardness of HV 850 is necessary to obtain wear resistance comparable to that of hard chromium.

The unlubricated wear rates of pins plated with electroless nickel containing 8.5 percent P against blocks of different metals determined in a testing device like the one used to obtain the data given in Table 4.8 are shown in Table 4.9 (58). Wear rates exceeding 10 mg/1000 cycles are considered to be unsatisfactory. It is thus seen that all the block materials, except chromium, which were tested against as-plated electroless nickel failed. Heat-treated, electroless nickel plated pins behave unsatisfactorily against chromium, stainless steel, and as-plated electroless nickel. The wear rates of blocks of steel and those coated with electroless nickel heat treated at 400 and 600° C against electroless nickel pins heat treated at 400 and 600° C were satisfactory. It is apparent that electroless nickel should be used cautiously under unlubricated conditions.

Table 4.9
Falex Unlubricated Wear Rates
Of Electroless Nickel Coated Pins (58)

Block material	Wear rates (wt. loss, mg/1000 cycles) As-plated	 Heat treated, 400° C	 Heat treated, 600° C
Steel	70	3	4
Cr	10	20	20
Stainless steel	F[*]	F	20
EN, as-plated	F	F	10
EN, heated treated, 400° C	75	5	5
EN, heat treated, 600° C	F	4	2

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[*] Failure load—22.5 kg; rotation—290 rpm.

In unlubricated Falex wear tests on blocks with a hardness of Rc 20 to 24, Ni-B plated pins from an acidic (DMAB) solution performed poorly as compared to those from a basic (sodium borohydride) solution, as well as Ni-P deposits from either acidic or alkaline sodium hypophosphite solutions. The data are shown in Table 4.10 (57). All deposits were heat treated for 1 hr at 400° C. The maximum load was 182 kg.

Some Taber abrasion test data (16) are presented in Table 4.11 for chromium and electroless nickel alloys containing 10 percent P or 5 percent B. The Taber Wear Index is the weight loss in mg per 1000 revolutions with a 1 kg load using resilient, abrasive (CS-10) wheels.

Table 4.10
Unlubricated Falex Wear and Hardness Data (59)

Solution	Knoop hardness, KN_{50}	Plated journal weight loss, mg	Time to failure, min
Acid Ni-P	1088	64	6*
Basic Ni-P	990	16	3*
Acid Ni-B	1284	419	—
Basic Ni-B	1195	68	7*

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*Maximum load 182 g.

Table 4.11
Taber Abrasion Data (16)

Heat treatment	Taber Wear Index*
Ni-P, as-plated	15-20
Ni-P, 1 hr, 288° C	10-15
Ni-P, 0.25-1 hr, 400° C	6
Ni-P, 0.25-1 hr, 600° C	4
Ni-B, as-plated	8-12
Ni-B, 1 hr, 400° C	4
Chromium	2

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*Taber wear index = mg/weight loss/100 revs, CS-10 wheels, 1 kg load.

It is apparent from Table 4.11 that the abrasion resistance increased with increasing heat treatment temperature. This improvement may be due to the larger grain size of the deposits. It is also apparent that Ni-B alloys are more abrasion resistant than Ni-P deposits. The best resistance to scoring (equal to that of chromium) was attained in Ni-P deposits heat treated for 2 hr at 289° C (60). In fretting wear tests it was found (61) that as-plated electroless nickel coatings containing 11 to 12 percent P on low alloy steel substrates behaved better than those heat treated to the maximum hardness. A minimum coating thickness of 25 μm (1 mil) was also found to be necessary.

Duplex coatings consisting of 29-μm-thick hard Ni-P with 6 percent P deposited over a 40-μm-thick, somewhat more ductile layer of Ni-P with 12 percent P have protected hydraulic equipment subjected severe wear and corrosion conditions (62).

The wear and abrasion applications of electroless nickel coatings can be summarized as follows:

- Coatings must be heat treated to a hardness greater than HV 800.
- Coating hardness on rotating parts should be greater than that of the mating surface.
- Phosphorus content should be greater than 10 percent.
- Contacting surfaces should be smooth and lubricated.
- Electroless nickel coatings are not suitable for use under high shear and load conditions.