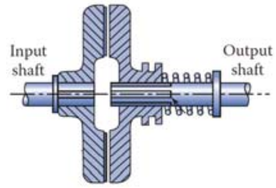
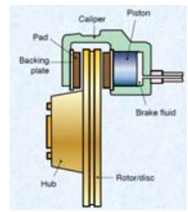
Brakes and Clutches

- **Clutch:** A device used to connect or disconnect a driven element from the driving element



- **Brake:** Device used to slow down the motion of a moving element or to bring it to a state of rest



- Operation of either of this requires an actuating force
- The actual action i.e. transfer of motion in a clutch or slowing down in a brake is effected through frictional forces

Brake Drum

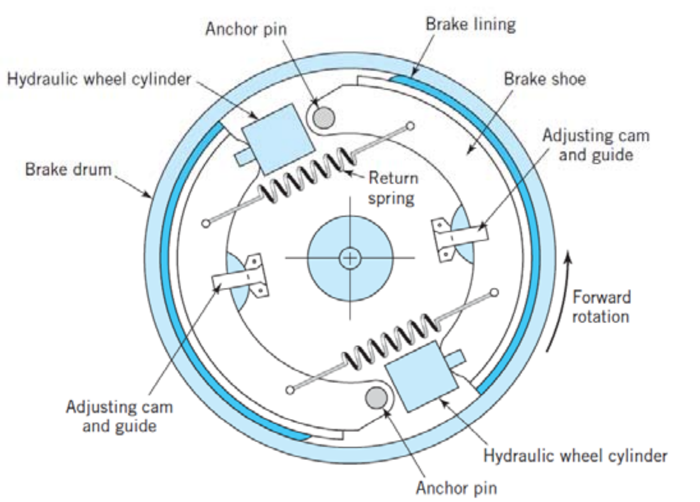


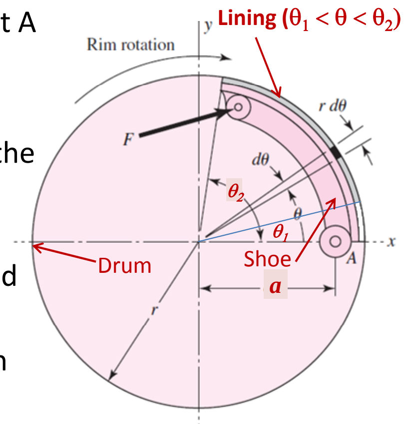
FIGURE 18.14
Automotive brake with two hydraulic wheel cylinders. Both shoes are self-energizing for forward car motion. (Courtesy Chrysler Corporation.)

Typical Drum Brake Parts

Internal shoe brakes or drum brakes

- Rear brakes of most cars are of this type

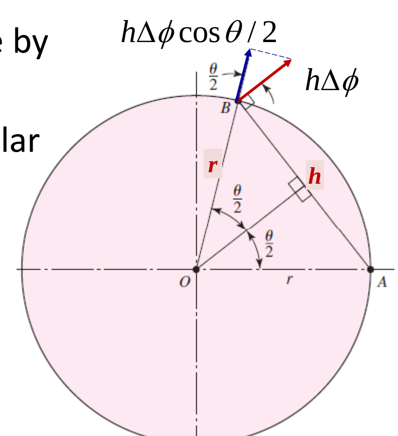
- The internal arc type shoe is hinged at A
- It is a floating element that can pivot about A
- The force F presses the shoe against the internal surface of the drum during braking
- The frictional lining material is pressed against the drum
- The resulting normal pressure at each point generates frictional force
- The net frictional torque due to this decelerates the drum



Drum width: b

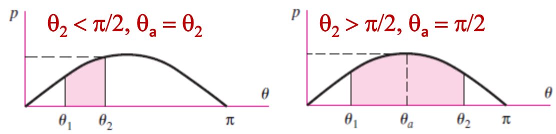
- Consider a rotation of the shoe by $\Delta\phi$ about A
- Point B moves $h\Delta\phi$ perpendicular to AB
- The radial component of this movement is $h\Delta\phi\cos\theta/2$

$$u_r = (2r\sin\theta/2)\Delta\phi\cos\theta/2$$
$$u_r = r\Delta\phi\sin\theta$$



- The amount of radial movement at each point is proportional to $\sin\theta$
- Assume pressure (p) at each point is proportional to u_r

$$p = \frac{p_a}{\sin\theta_a}\sin\theta;\ p_a \text{ is maximum pressure at } \theta = \theta_a$$



- Friction is proportional to normal pressure, hence providing liner close to θ=0 is not very effective as *p* is close to zero

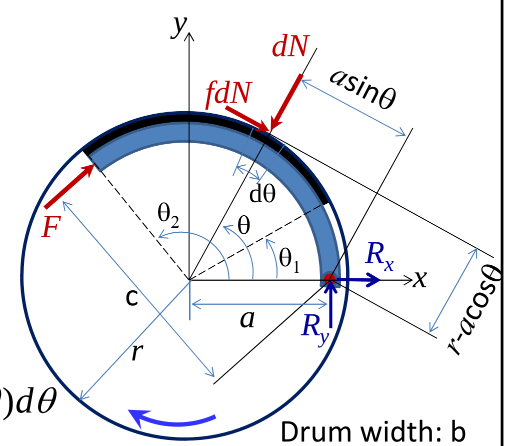
$$dN = pbrd\theta = \frac{p_a br}{\sin\theta_a}\sin\theta d\theta$$

$$dM_N = dNa\sin\theta$$

$$M_N = \frac{p_a bra}{\sin\theta_a}\int_{\theta_1}^{\theta_2}\sin^2\theta d\theta$$

$$dM_f = fdN(r - a\cos\theta)$$

$$M_f = \frac{fp_a br}{\sin\theta_a}\int_{\theta_1}^{\theta_2}\sin\theta(r - a\cos\theta)d\theta$$



- Moment balance about the hinge

$$Fc + M_f - M_N = 0 \Rightarrow F = (M_N - M_f)/c$$

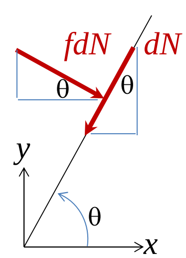
- For $M_N = M_f$, F=0; For $M_N < M_f$ the brake is self locking
- Self energizing brake: Frictional moment M_f drags the shoe towards the drum- Depends on the dimension *a*

Torque on the drum is

$$T = \int_{\theta_1}^{\theta_2} frdN = \frac{fp_a br^2}{\sin\theta_a}(\cos\theta_1 - \cos\theta_2)$$

$$R_x = \int_{\theta_1}^{\theta_2}(dN\cos\theta - fdN\sin\theta)d\theta - F_x$$

$$R_y = \int_{\theta_1}^{\theta_2}(dN\sin\theta + fdN\cos\theta)d\theta - F_y$$

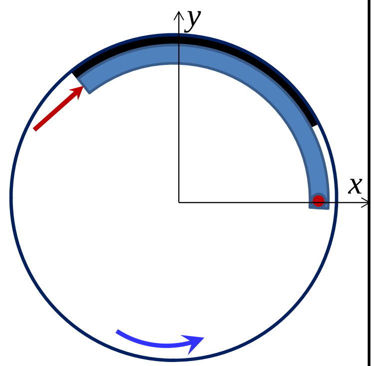


- For CCW rotation

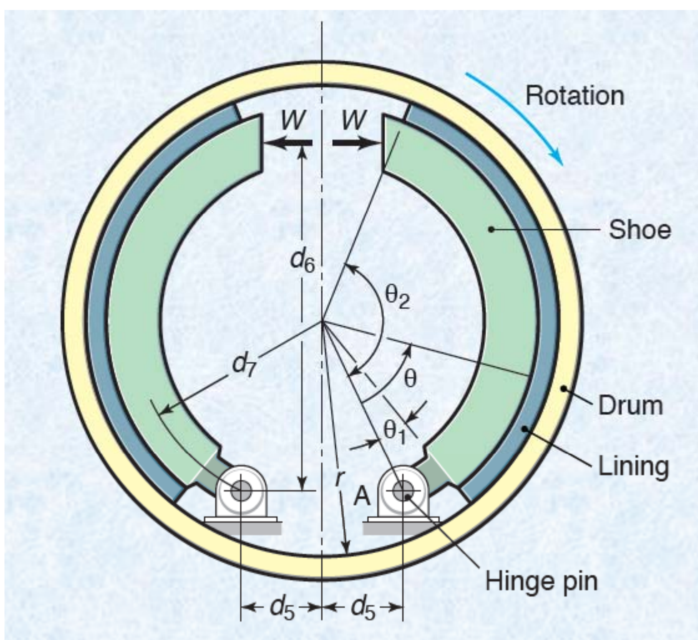
$$F = (M_N + M_f)/c$$

$$R_x = \int_{\theta_1}^{\theta_2} (dN\cos\theta + fdN\sin\theta)d\theta - F_x$$

$$R_y = \int_{\theta_1}^{\theta_2} (dN\sin\theta - fdN\cos\theta)d\theta - F_y$$



- Assumptions:
  - Centrifugal effects neglected
  - Shoe is assumed to be rigid
  - Coefficient of friction does not vary with normal pressure



External shoe brakes

CW Rotation

$$F = (M_N + M_f)/c$$

$$R_x = \int_{\theta_1}^{\theta_2} (dN\cos\theta + fdN\sin\theta)d\theta - F_x$$

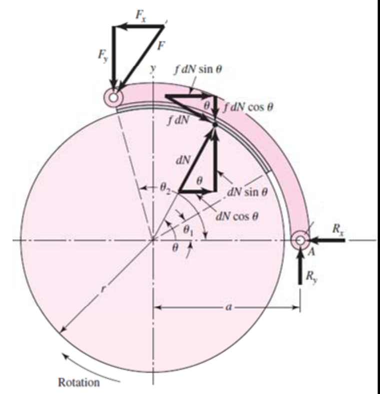
$$R_y = \int_{\theta_1}^{\theta_2} (dN\sin\theta - fdN\cos\theta)d\theta + F_y$$

CCW Rotation

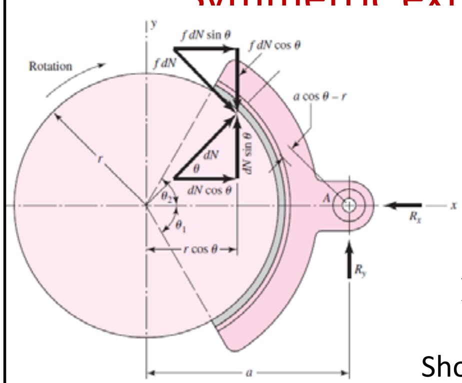
$$F = (M_N - M_f)/c$$

$$R_x = \int_{\theta_1}^{\theta_2} (dN\cos\theta - fdN\sin\theta)d\theta - F_x$$

$$R_y = \int_{\theta_1}^{\theta_2} (dN\sin\theta + fdN\cos\theta)d\theta - F_y$$



Symmetric external shoe brake



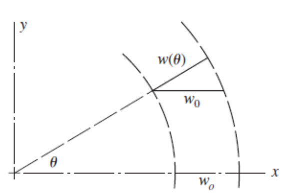
$$u_r = -\Delta x\cos\theta;\; p = p_a\cos\theta$$

$$dN = p_a br\cos\theta d\theta;\; M_N = 0$$

$$M_f = 2fp_a br\int_0^{\theta_2} (a\cos^2\theta - r\cos\theta)d\theta$$

$$\text{For } a = \frac{4r\sin\theta_2}{2\theta_2 + \sin 2\theta_2};\; M_f = 0$$

Shoe will be vertical and wear will be symmetrical

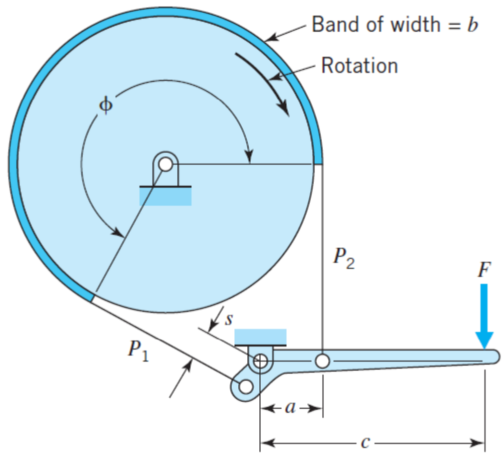


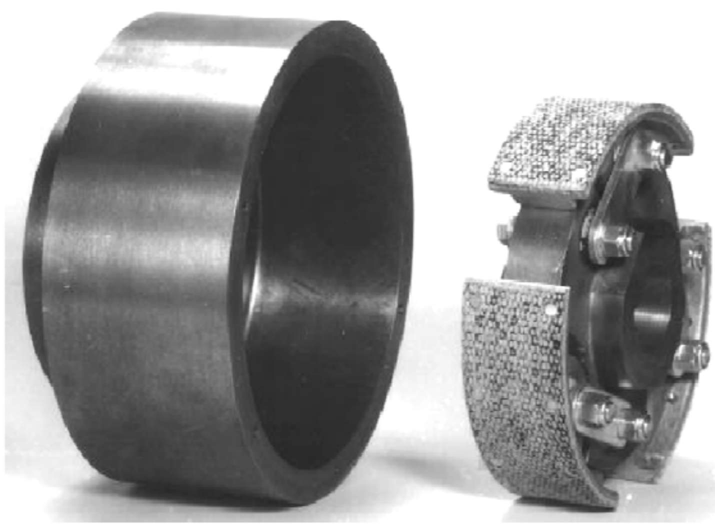
$$R_x = \frac{p_a br}{2}(2\theta_2 + \sin 2\theta_2)$$

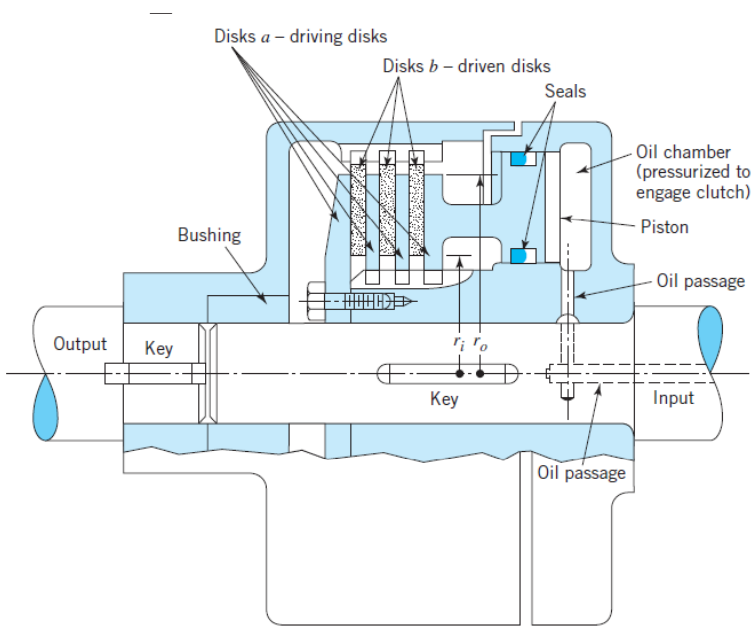
$$R_y = \frac{p_a brf}{2}(2\theta_2 + \sin 2\theta_2)$$

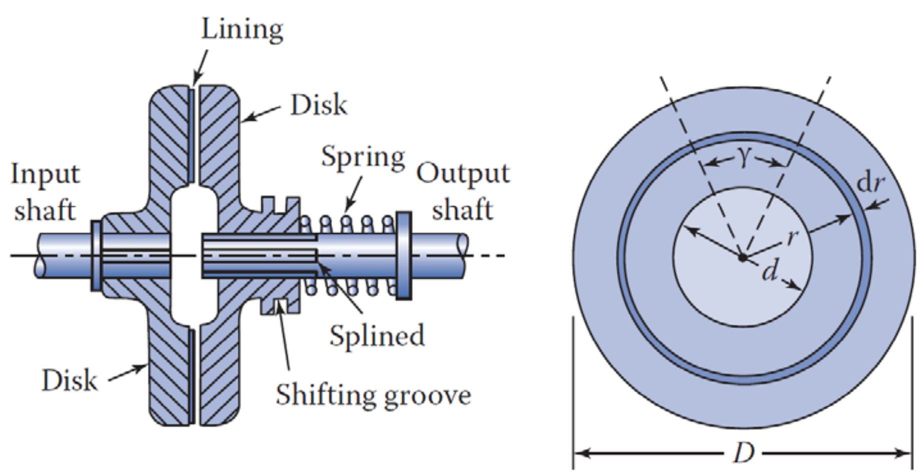
$$T = 2fp_a br^2\sin\theta_2$$

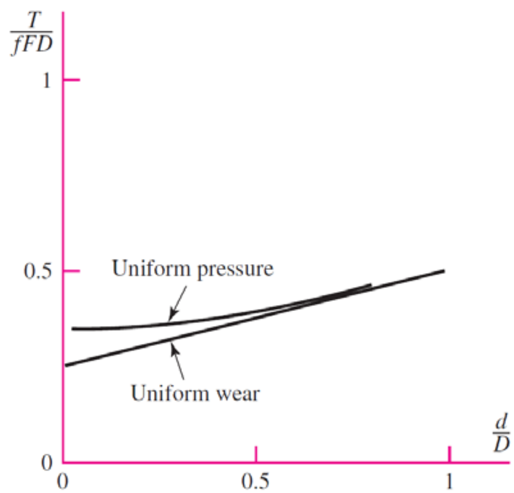
Band brakes

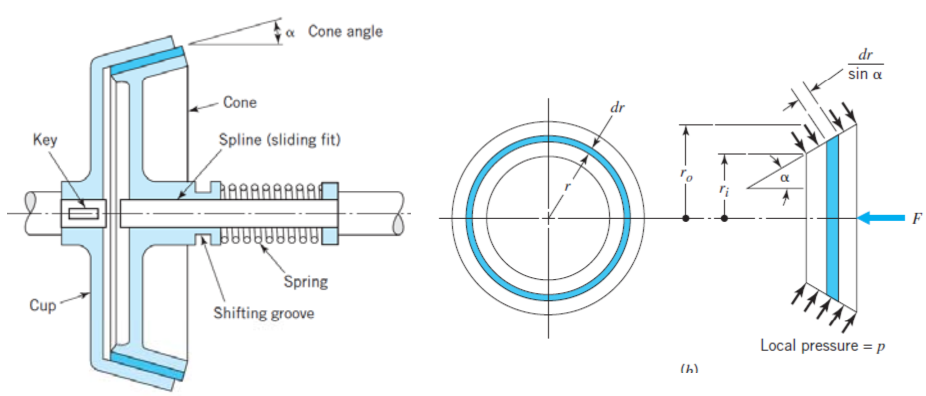


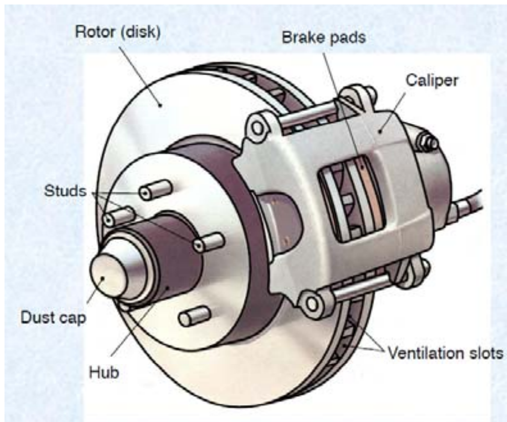


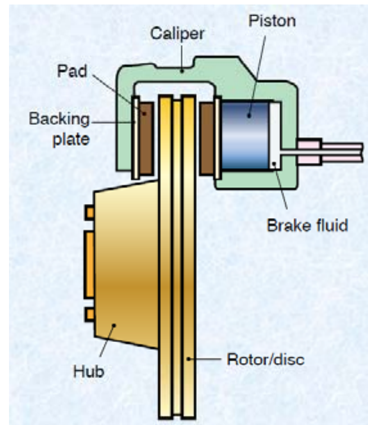

Disks a – driving disks
Disks b – driven disks
Seals
Oil chamber (pressurized to engage clutch)
Piston
Oil passage
Bushing
Output
Key
r_i r_o
Key
Input
Oil passage


Lining
Disk
Input shaft
Spring
Output shaft
Splined
Disk
Shifting groove
γ
dr
r
d
D


$\frac{T}{fFD}$
1
0.5
0
Uniform pressure
Uniform wear
$\frac{d}{D}$
0
0.5
1


α Cone angle
Cone
Key
Spline (sliding fit)
Spring
Cup
Shifting groove
dr
r
r_o
r_i
α
$\frac{dr}{\sin \alpha}$
F
Local pressure = p
(b)





Design aspects

- **Shoe versus disc brakes**
  - In shoe brakes there is self energization which can lower the actuation force.
  - But if friction coefficient decreases the self energization also decreases and this increases the actuation force.
  - In disc brakes there is no self energization and therefore the actuation force is not affected by friction
- **Disc brakes: Advantages**
  - Steady braking
  - Easy ventilation
  - Thrust loads self balanced
  - Simple design
  - Better heat dissipation

Design considerations

- Torque required to accelerate or decelerate the system
- Time required to accomplish this change
- Number of cycles of operation
- Inertia of the rotating parts
- Energy dissipation capacity: environment, temperature, cooling rate
- Physical size and interfacing aspects
- Life and required reliability
- Cost

- Friction material
  - High and reproducible coefficient of friction
  - Impervious to moisture
  - Ability to withstand high temperature
  - Good thermal conductivity, diffusivity and heat capacity
  - Good resilience
  - Good resistance to wear
  - Environmental compatibility
  - Flexibility

Table 16–3

Characteristics of Friction Materials for Brakes and Clutches *Sources:* Ferodo Ltd., Chapel-en-le-frith, England; Scan-pac, Mequon, Wisc.; Raybestos, New York, N.Y. and Stratford, Conn.; Gatke Corp., Chicago, Ill.; General Metals Powder Co., Akron, Ohio; D. A. B. Industries, Troy, Mich.; Friction Products Co., Medina, Ohio.

Material	Friction Coefficient f	Maximum Pressure p_{max}, psi	Maximum Temperature Instantaneous, °F	Maximum Temperature Continuous, °F	Maximum Velocity V_{max}, ft/min	Applications
Cermet	0.32	150	1500	750		Brakes and clutches
Sintered metal (dry)	0.29–0.33	300–400	930–1020	570–660	3600	Clutches and caliper disk brakes
Sintered metal (wet)	0.06–0.08	500	930	570	3600	Clutches
Rigid molded asbestos (dry)	0.35–0.41	100	660–750	350	3600	Drum brakes and clutches
Rigid molded asbestos (wet)	0.06	300	660	350	3600	Industrial clutches
Rigid molded asbestos pads	0.31–0.49	750	930–1380	440–660	4800	Disk brakes
Rigid molded nonasbestos	0.33–0.63	100–150		500–750	4800–7500	Clutches and brakes
Semirigid molded asbestos	0.37–0.41	100	660	300	3600	Clutches and brakes
Flexible molded asbestos	0.39–0.45	100	660–750	300–350	3600	Clutches and brakes
Wound asbestos yarn and wire	0.38	100	660	300	3600	Vehicle clutches
Woven asbestos yarn and wire	0.38	100	500	260	3600	Industrial clutches and brakes
Woven cotton	0.47	100	230	170	3600	Industrial clutches and brakes
Resilient paper (wet)	0.09–0.15	400	300		$PV < 500\,000$ psi · ft/min	Clutches and transmission bands

Properties of brake linings

	Woven Lining	Molded Lining	Rigid Block
Compressive strength, kpsi	10–15	10–18	10–15
Compressive strength, MPa	70–100	70–125	70–100
Tensile strength, kpsi	2.5–3	4–5	3–4
Tensile strength, MPa	17–21	27–35	21–27
Max. temperature, °F	400–500	500	750
Max. temperature, °C	200–260	260	400
Max. speed, ft/min	7500	5000	7500
Max. speed, m/s	38	25	38
Max. pressure, psi	50–100	100	150
Max. pressure, kPa	340–690	690	1000
Frictional coefficient, mean	0.45	0.47	0.40–45

Friction Materials for Clutches

Material	Friction Coefficient		Max. Temperature		Max. Pressure	
	Wet	Dry	°F	°C	psi	kPa
Cast iron on cast iron	0.05	0.15–0.20	600	320	150–250	1000–1750
Powdered metal* on cast iron	0.05–0.1	0.1–0.4	1000	540	150	1000
Powdered metal* on hard steel	0.05–0.1	0.1–0.3	1000	540	300	2100
Wood on steel or cast iron	0.16	0.2–0.35	300	150	60–90	400–620
Leather on steel or cast iron	0.12	0.3–0.5	200	100	10–40	70–280
Cork on steel or cast iron	0.15–0.25	0.3–0.5	200	100	8–14	50–100
Felt on steel or cast iron	0.18	0.22	280	140	5–10	35–70
Woven asbestos* on steel or cast iron	0.1–0.2	0.3–0.6	350–500	175–260	50–100	350–700
Molded asbestos* on steel or cast iron	0.08–0.12	0.2–0.5	500	260	50–150	350–1000
Impregnated asbestos* on steel or cast iron	0.12	0.32	500–750	260–400	150	1000
Carbon graphite on steel	0.05–0.1	0.25	700–1000	370–540	300	2100

*The friction coefficient can be maintained with ±5 percent for specific materials in this group.