Determining the Coefficient of Friction

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Different types of coefficient

The different types of friction are static, kinetic, deformation, molecular and rolling. Each has its own coefficient of friction.

Static coefficient

Static friction is the force that holds back a stationary object up to the point that it just starts moving. Thus, the static coefficient of friction concerns the force restricting the movement of an object that is stationary on a relatively smooth, hard surface.

Kinetic coefficient

Once you overcome static friction, kinetic friction is the force holding back regular motion. This, kinetic friction coefficient concerns the force restricting the movement of an object that is sliding on a relatively smooth, hard surface.

Friction Center Coefficient Database

The table below gives static and kinetic friction coefficients for various combinations of materials. These values are for reference only and actual values will vary depending on the particular application conditions.

Friction Couple	Conditions	static coefficient	kinetic coefficient
aluminum / aluminum	oxidizing environment	1.9	
aluminum / steel		0.61	0.47
automotive brake pad / cast iron	humid environment		0.2 - 0.5
brick / brick		0.65	
carbon composite / carbon composite	inert environment		0.5 - 1.2
carbon composite / carbon composite	humid environment		0.1 - 0.5
copper / copper	inert environment	4.0	
copper / copper	oxidizing environment	1.6	
copper / steel		0.53	0.36
cortical bone / cencellous bone	saline lubrication	0.61	
diamond / diamond	clean	0.1	
diamond / diamond	lubricated	0.05 - 0.1	
glass / glass	clean	0.94	0.40
glass / glass	lubricated	0.2 - 0.3	
glass / metal	clean	0.5 - 0.7	
gold / gold	inert environment	4.0	
gold / gold	humid environment	2.5	
ice / ice		0.10	0.03
iron / iron	oxidizing or humid environment	1.2	
leather / metal		0.55	
metal / metal	lubricated	0.15	0.05

mica / mica	clean, fresh cleave	1.0	
mica / mica		0.2 - 0.4	
nickel / nickel	inert environment	5.0	
nickel / nickel	oxidizing environment	3.0	
nickel / nickel	humid environment	1.6	
nylon / nylon	clean	0.20	
rubber / concrete	varying	1.00 - 4.00	0.80
sapphire / sapphire	non-lubricated	0.2	
sapphire / steel	non-lubricated	0.15	
Silver / Silver	oxidizing or humid environment	1.5	
steel / steel		0.74	0.57
synovial joints (humans)		0.01	0.003
teflon / teflon		0.04	0.04
tungsten carbide / graphite		0.62	
wood / stone		0.40	
wood / wood		0.25 - 0.5	0.20

Deformation coefficient
The deformation coefficient of friction concerns the force restricting the movement of an object that is sliding or rolling and one or both surfaces are relatively soft and deformed by the forces.
Molecular coefficient
Molecular coefficient of friction concerns the force restricting the movement of an object that is sliding on an extremely smooth surface or where a fluid is involved.
Rolling coefficient
The rolling coefficient of friction combines static, deformation and molecular coefficients of friction. This coefficient of friction can be made quite low.

When a wheel rolls along a surface, the resistive force of rolling friction can slow down the motion. Rolling friction is usually much less than sliding or kinetic friction, but it can vary dramatically, depending on the wheel and surface materials. The deformation of the surfaces in contact and adhesive forces between those surfaces combine to create rolling friction.

Although static friction comes into play when a wheel starts to roll, it has a negligible effect once the wheel is continuously rolling. The friction acting on a rolling wheel can be quite small, giving it an enormous advantage over trying to move an object by sliding it.

The coefficient of rolling friction for a tire or wheel on a hard surface is 100 to 1000 times less than that of sliding or kinetic friction on that same surface. The chart below illustrates that fact.

Coefficient of Friction		
Surfaces	**Rolling Friction**	**Kinetic Friction**
Low-rolling resistance car tire on dry pavement	0.006-0.01	0.8
Ordinary car tire on dry pavement	0.015	0.8
Truck tire on dry pavement	0.006-0.01	0.8
Train wheel on steel track	0.001	0.1

You can see that the train wheel has the lowest rolling friction, but it has the poorest stopping ability.

Major factor is deformation

Since no surfaces are perfectly hard, there is some deformation in both the wheel and the surface on which it is rolling. This is a major factor in rolling friction.

Tire is flattened on bottom

Deformations can be easily illustrated by considering an automobile tire.

When weight is applied to a tire, the surface touching the ground flattens. If the car is driving on soft earth, that surface is also deformed by the weight of the automobile. Pavement deforms a small amount, but you cannot really notice it.

The deformations of the wheel or tire and the surface on which it is rolling will result in a resistive force that will slow down the object. It is like the wheel must "plow through" the surface it is rolling on. Energy is dissipated in deforming the wheel and the surface. This loss of energy is converted to a resistive force, thus slowing down the rolling motion.

Friction equation

The equation to describe the resistive force of friction is the same as for static and kinetic friction, and is essentially independent of the area in contact.

$$\mathbf{Fr = u \times W}$$

where **u** is the coefficient of rolling friction. This coefficient is a function of the weight **W** and the elasticity of the materials, as well as the static friction between the materials.

In the case of an automobile tire on pavement, **u** is a function of the inflation or the tire, the weight of the car, the type of rubber used, and the static friction between the rubber and the road.

Adhesion effect

Depending on the materials involved, there is also a molecular adhesion effect that adds to the rolling friction. This is especially seen in race car tires, which are made of a soft rubber. They use the stickiness of the rubber to improve traction, but it also increases rolling friction over a harder rubber.

Expends energy

No matter what the materials, there is a molecular attraction when they are pressed together. During the rolling action, the surfaces are pulled apart at the back edge, and energy must be expended to pull the surfaces apart.

Dependent on area

Static and kinetic friction are independent of the area in contact. This is also somewhat true for rolling friction caused by deformations. But the part of rolling friction that is cause by adhesive forces is very dependent on the area of the surfaces in contact. The equations for the adhesive part of rolling friction are highly complex. Often the coefficient of adhesive friction is determined empirically, through experimental measurements.

In conclusion

There are many types of coefficient of friction, but the main ones are static and kinetic. You can determine the coefficient by direct measurements or by clever indirect means. There are charts with the coefficients of friction available for reference.

Material 1	Material 2	Coefficient Of Friction	
		Static	Kinetic
Aluminum	Aluminum	1.05-1.35	1.4
Aluminum	Mild Steel	0.61	0.47
Brake Material	Cast Iron	0.4	
Brake Material	Cast Iron (Wet)	0.2	
Brass	Cast Iron		0.3
Brick	Wood	0.6	
Bronze	Cast Iron		0.22
Bronze	Steel		
Cadmium	Cadmium	0.5	
Cadmium	Mild Steel		0.46
Cast Iron	Cast Iron	1.1	0.15
Cast Iron	Oak		0.49
Chromium	Chromium	0.41	
Copper	Cast Iron	1.05	0.29
Copper	Copper	1	
Copper	Mild Steel	0.53	0.36
Copper	Steel		0.8
Copper	Steel (304 stainless)	0.23	0.21
Copper-Lead Alloy	Steel	0.22	
Diamond	Diamond	0.1	
Diamond	Metal	0.1 -0.15	
Glass	Glass	0.9 - 1.0	0.4
Glass	Metal	0.5 - 0.7	

Material 1	Material 2	Coefficient Of Friction	
		Static	Kinetic
Glass	Nickel	0.78	0.56
Graphite	Graphite	0.1	
Graphite	Steel	0.1	
Graphite (In vacuum)	Graphite (In vacuum)	0.5 - 0.8	
Hard Carbon	Hard Carbon	0.16	
Hard Carbon	Steel	0.14	
Iron	Iron	1	
Lead	Cast Iron		0.43
Lead	Steel		1.4
Leather	Wood	0.3 - 0.4	
Leather	Metal(Clean)	0.6	
Leather	Metal(Wet)	0.4	
Leather	Oak (Parallel grain)	0.61	0.52
Magnesium	Magnesium	0.6	
Nickel	Nickel	0.7-1.1	0.53
Nickel	Mild Steel		0.64;
Nylon	Nylon	0.15 - 0.25	
Oak	Oak (parallel grain)	0.62	0.48
Oak	Oak (cross grain)	0.54	0.32
Platinum	Platinum	1.2	
Plexiglas	Plexiglas	0.8	
Plexiglas	Steel	0.4 - 0.5	
Polystyrene	Polystyrene	0.5	

Material 1	Material 2	Coefficient Of Friction	
		Static	Kinetic
Polystyrene	Steel	0.3-0.35	
Polythene	Steel	0.2	
Rubber	Asphalt (Dry)		0.5-0.8
Rubber	Asphalt (Wet)		0.25-0.75
Rubber	Concrete (Dry)		0.6-0.85
Rubber	Concrete (Wet)		0.45-0.75
Sapphire	Sapphire	0.2	
Silver	Silver	1.4	
Sintered Bronze	Steel	-	
Solids	Rubber	1.0 - 4.0	
Steel	Aluminium Bros	0.45	
Steel	Brass	0.35	
Steel(Mild)	Brass	0.51	0.44
Steel (Mild)	Cast Iron		0.23
Steel	Cast Iron	0.4	
Steel	Copper Lead Alloy	0.22	
Steel (Hard)	Graphite	0.21	
Steel	Graphite	0.1	
Steel (Mild)	Lead	0.95	0.95
Steel (Mild)	Phos. Bros		0.34
Steel	Phos Bros	0.35	
Steel(Hard)	Polythened	0.2	
Steel(Hard)	Polystyrene	0.3-0.35	

Material 1	Material 2	Coefficient Of Friction	
		Static	Kinetic
Steel (Mild)	Steel (Mild)	0.74	0.57
Steel (Mild)	Steel (Mild)	-	0.62
Steel(Hard)	Steel (Hard)	0.78	0.42
Steel	Zinc (Plated on steel)	0.5	0.45
Teflon	Steel	0.04	
Teflon	Teflon	0.04	
Tin	Cast Iron		0.32
Titanium Alloy Ti-6Al-4V(Grade 5)	Aluminium Alloy 6061-T6	0.41	0.38
Titanium Alloy Ti-6Al-4V(Grade 5)	Titanium Alloy Ti-6Al-4V(Grade 5)	0.36	0.3
Titanium Alloy Ti-6Al-4V(Grade 5)	Bronze	0.36	0.27
Tungsten Carbide	Tungsten Carbide	0.2-0.25	
Tungsten Carbide	Steel	0.4 - 0.6	
Tungsten Carbide	Copper	0.35	
Tungsten Carbide	Iron	0.8	
Wood	Wood(clean)	0.25 - 0.5	
Wood	Wood (Wet)	0.2	
Wood	Metals(Clean)	0.2-0.6	
Wood	Metals (Wet)	0.2	
Wood	Brick	0.6	
Wood	Concrete	0.62	
Zinc	Zinc	0.6	
Zinc	Cast Iron	0.85	0.21