MACHINE THEORY
Bachelor in Mechanical Engineering

FRICTION. LUBRICATION. BEARINGS

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Friction

Friction - the force resisting the relative motion of solid surfaces, fluid layers or material elements sliding against each other.

Basic laws of friction:

1. The frictional force F between solid bodies is proportional to the normal force between the surfaces
2. The frictional force F is independent of the apparent area of contact

Friction between two surfaces converts kinetic energy into heat.

Friction produces wear of contact surfaces.

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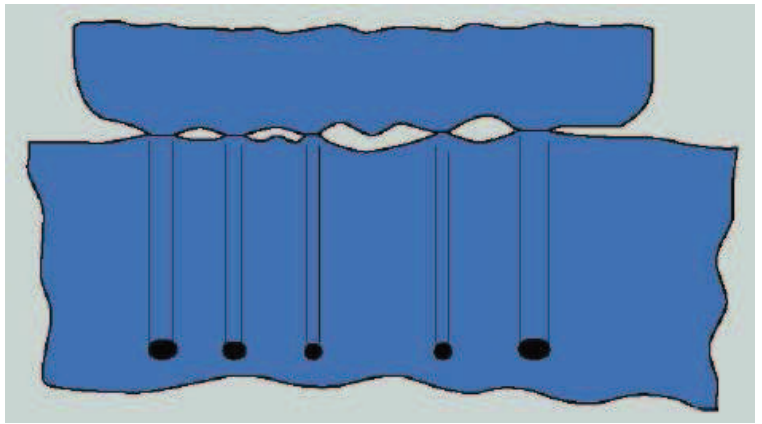
Coefficient of Friction

The coefficient of friction (μ) - represents the friction between two surfaces in contact

Depends on:

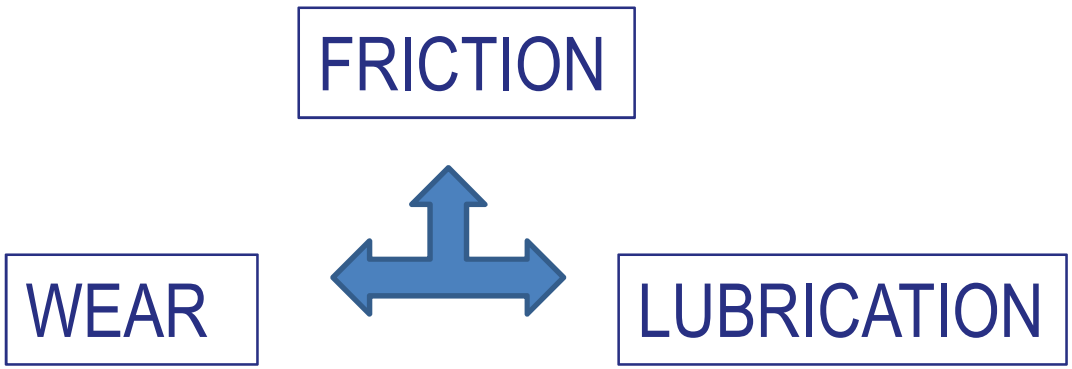
- the nature of contact surfaces
- the state of contact surfaces
- the relative displacement of contact surfaces
- the duration of friction

The coefficient of friction is determined experimentally and the values are given in handbooks.



Tribology

Tribology - the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear.



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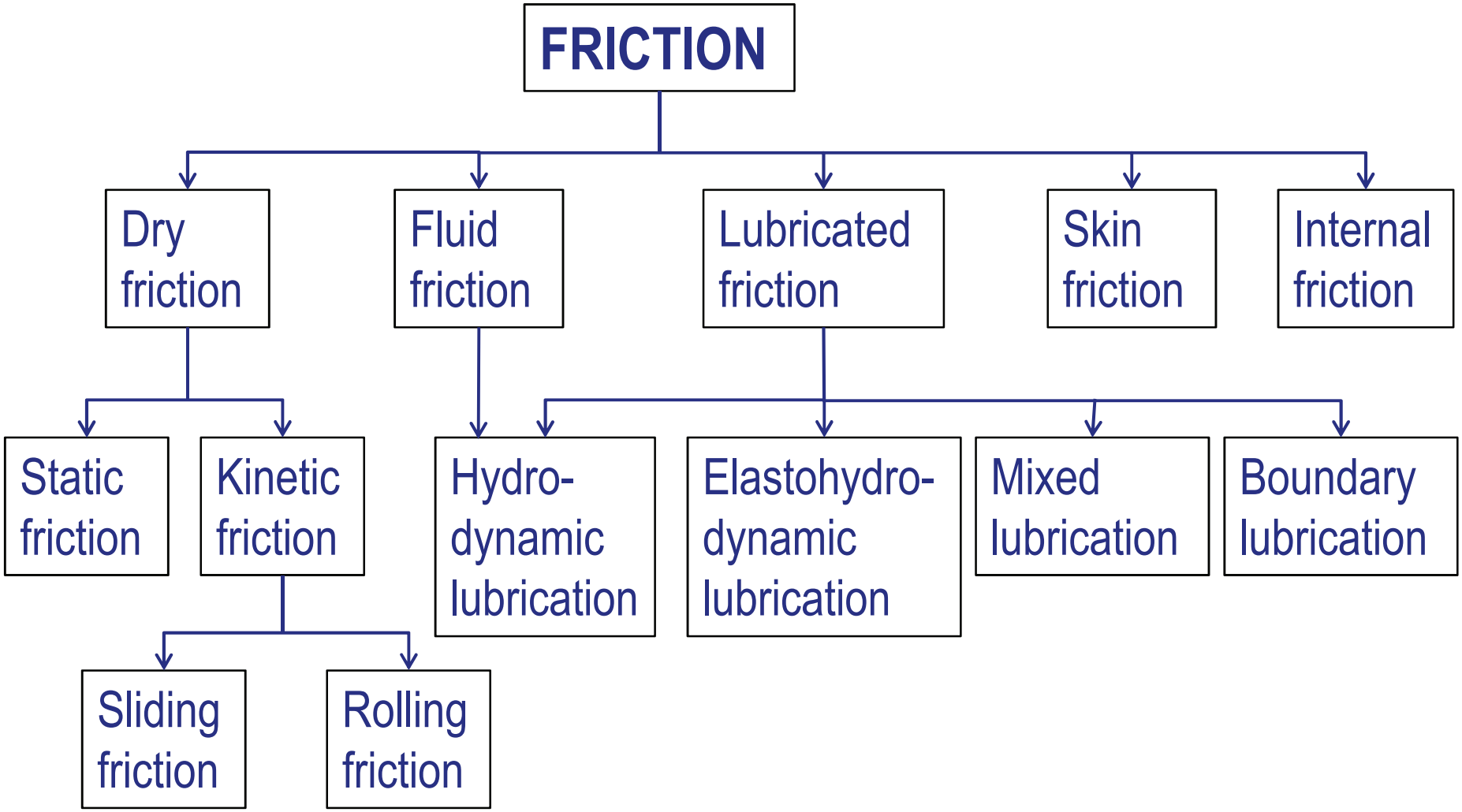
Classification of Friction



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Types of Friction

1. Dry friction - resists relative lateral motion of two solid surfaces in contact
2. Fluid friction - describes the friction between layers within a viscous fluid that are moving relative to each other.
3. Lubricated friction - a case of fluid friction where a fluid separates two solid surfaces
4. Skin friction - a component of drag, the force resisting the motion of a solid body through a fluid
5. Internal friction - the force resisting motion between the particles of a solid material while it deforms

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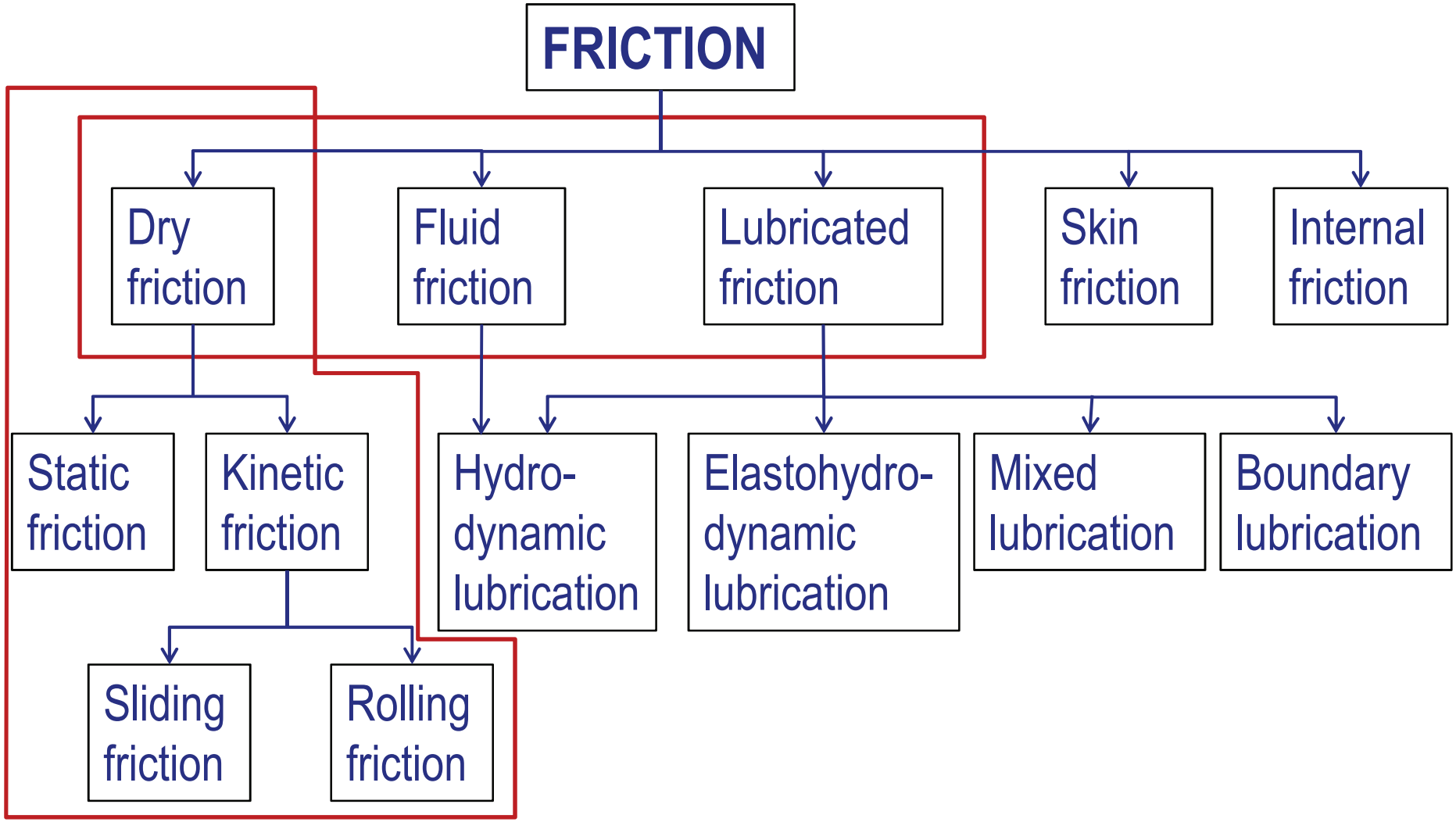
Classification of Friction

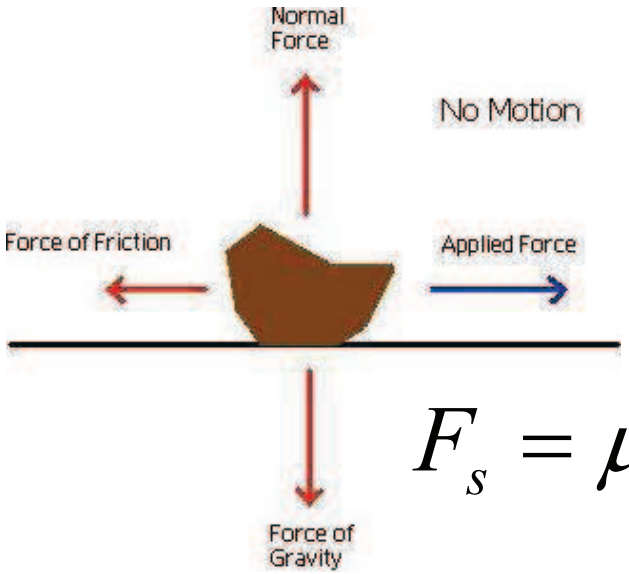


Dry Friction

DRY FRICTION

Static friction

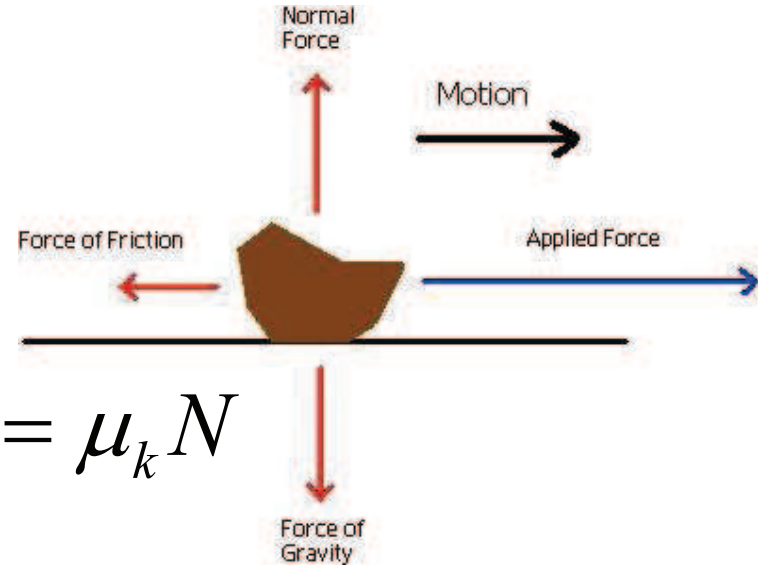
The force that resists the initiation of sliding motion



$$F_s = \mu_s N$$

Kinetic friction

Occurs when two objects are moving relative to each other



$$F_k = \mu_k N$$

$$\boxed{\mu_s > \mu_k}$$

Examples of Coefficient of Friction

Coefficients of friction for dry friction:

Materials	Coeff. of Static Friction μ_s	Coeff. of Kinetic Friction μ_k
Steel on Steel	0.74	0.57
Aluminum on Steel	0.61	0.47
Copper on Steel	0.53	0.36
Rubber on Concrete	1.0	0.8
Wood on Wood	0.25-0.5	0.2
Glass on Glass	0.94	0.4
Waxed wood on Wet snow	0.14	0.1
Waxed wood on Dry snow	-	0.04
Metal on Metal (lubricated)	0.15	0.06
Ice on Ice	0.1	0.03
Teflon on Teflon	0.04	0.04
Synovial joints in humans	0.01	0.003

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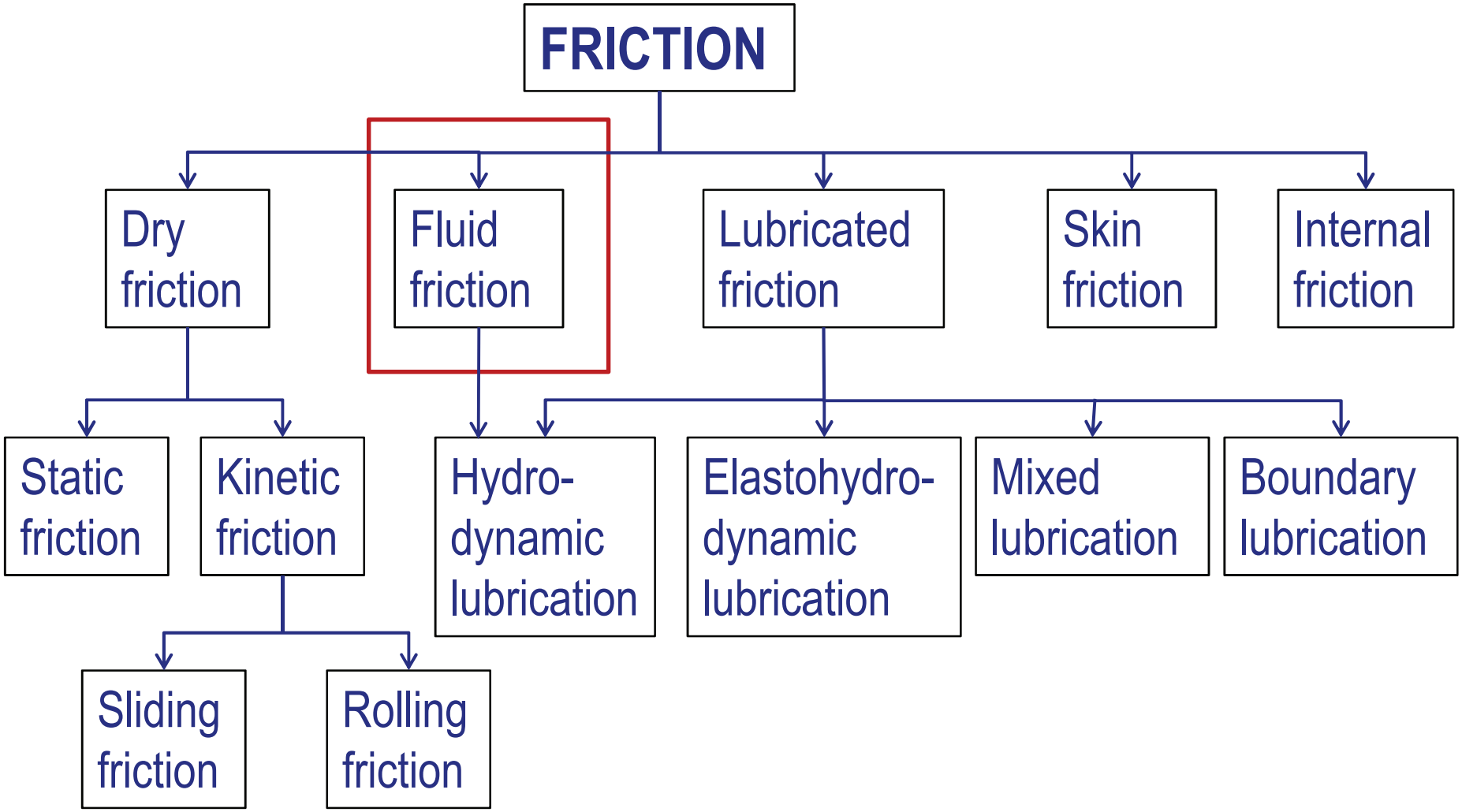
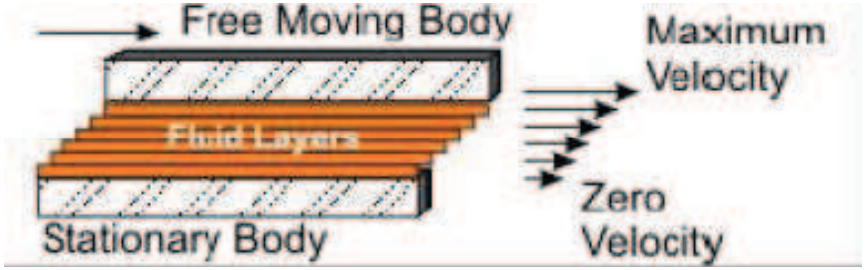
Classification of Friction



Fluid friction

Fluid friction - occurs between layers within a fluid that are moving relative to each other



Viscosity - describes a fluid's internal resistance to flow, is a measure of fluid friction

$$F_{viscous} = \mu_{viscous} N$$

Low viscosity

High viscosity

Dry Friction vs Fluid Friction

Dry friction:

- Depends on the normal force N
- Fairly stable with the relative velocity
- Independent of contact surface area
- Depends on the state and nature of the contact surfaces

Fluid (viscous) friction:

- Does not depend on the normal force N
- Increases with relative velocity
- Increases with the contact surface area
- Independent from contact surface type

Fluid friction

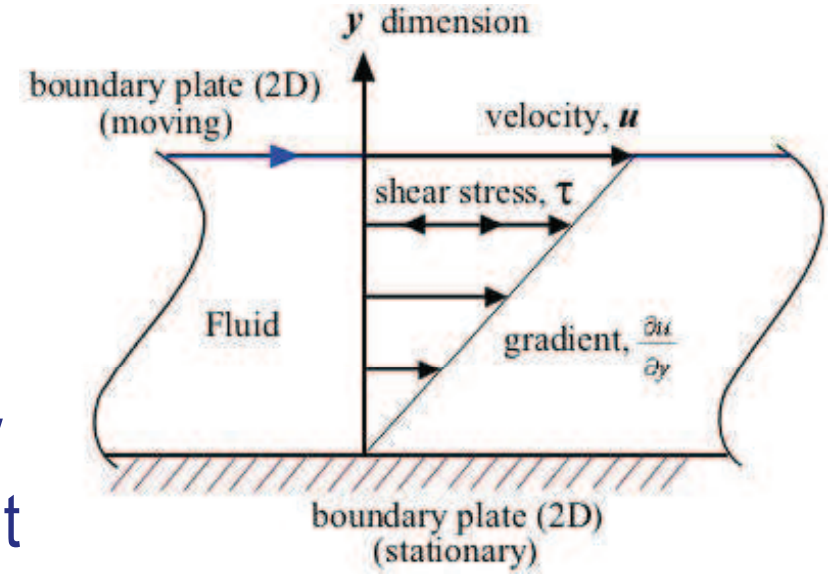
Newton law:

$$\tau = \eta \frac{\partial u}{\partial y}$$

Shear stress

viscosity of the fluid

velocity gradient

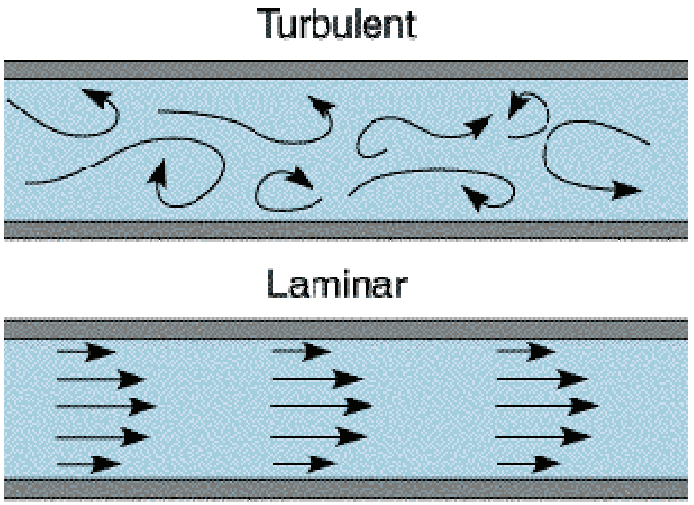


As: $\tau = \frac{F}{S}$ → $d\vec{F} = \eta \cdot ds \cdot \frac{d\vec{u}}{dy}$

Fluid friction

Hypothesis: Laminar flow

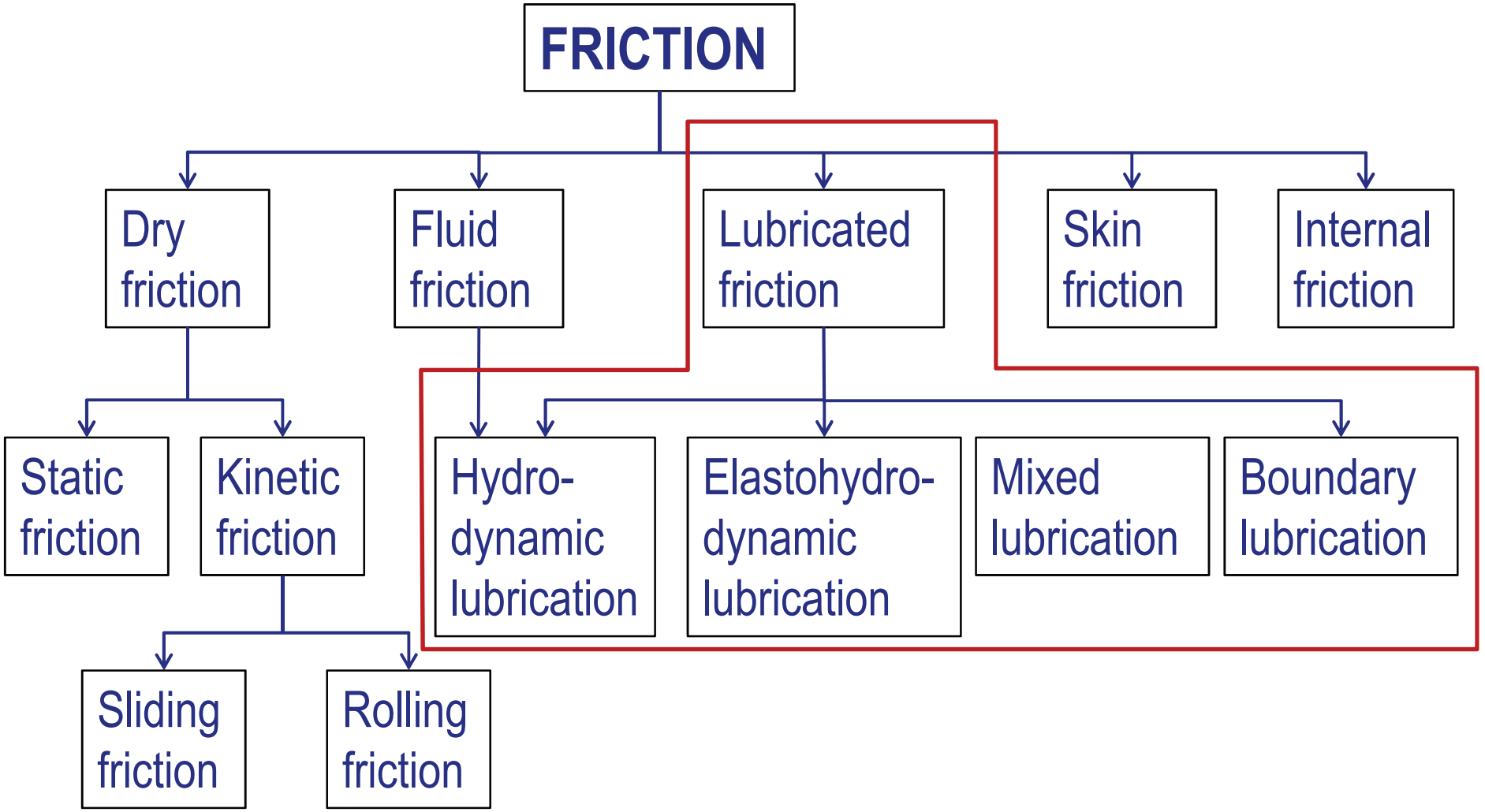
According to Newton law:



$$F = \eta S \frac{du}{dy}$$

$$F = \left(\eta \frac{S}{N} \frac{du}{dy} \right) N \quad \Rightarrow \quad \mu_{viscous} = \eta \frac{S}{N} \frac{du}{dy}$$

Lubricated Friction



Lubrication

Lubrication - process or technique employed to reduce wear of surfaces moving relative to each other by adding a substance called lubricant between the surfaces to carry or to help carry the load between the opposing surfaces

Objectives:

- reduce friction
- reduce wear
- decrease temperature
- transmit pressure
- protection from corrosion
- protection from contamination
- electric insulation

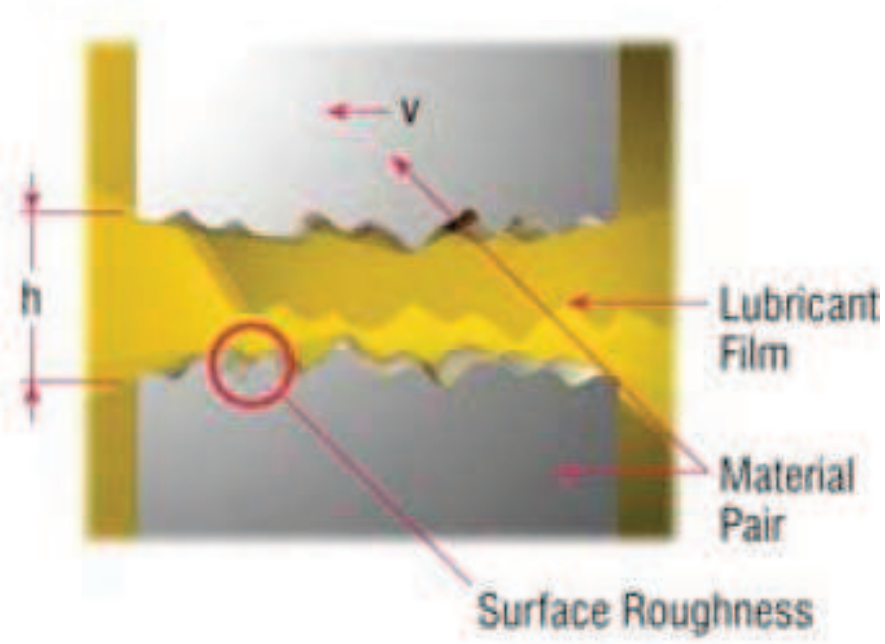
Regimes of Lubrication

Regimes of lubrication:

1. Hydrodynamic lubrication
2. Elastohydrodynamic lubrication
3. Mixed lubrication
4. Boundary lubrication

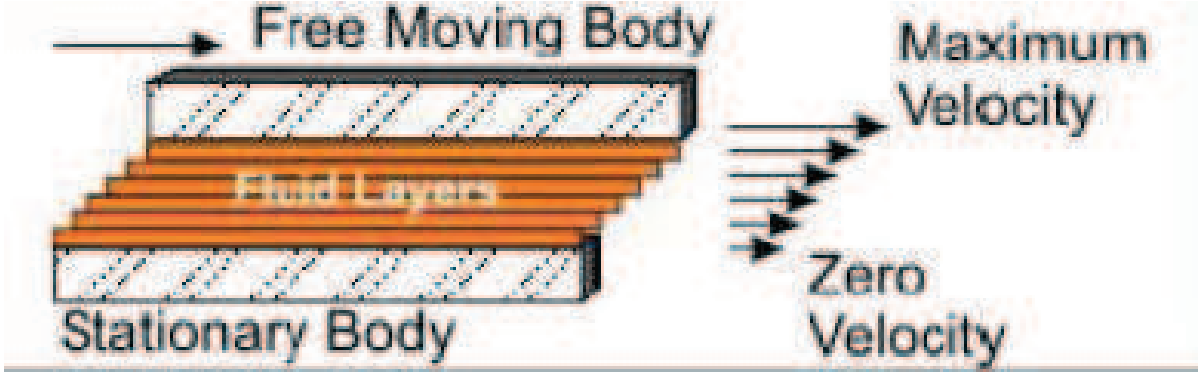
Depends on:

- viscosity of a lubricant
- relative velocity
- carried load
- state of the contact surface



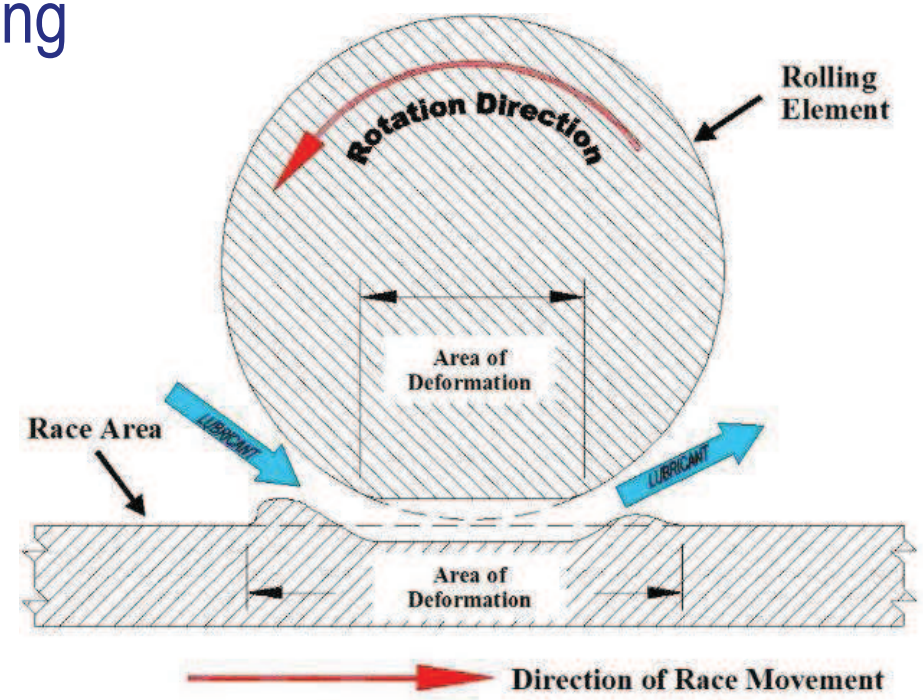
Hydrodynamic Lubrication

Hydrodynamic lubrication - through viscous forces the load is fully supported by the lubricant within the space between the parts in motion and solid-solid contact is avoided. ➔ **Fluid friction**



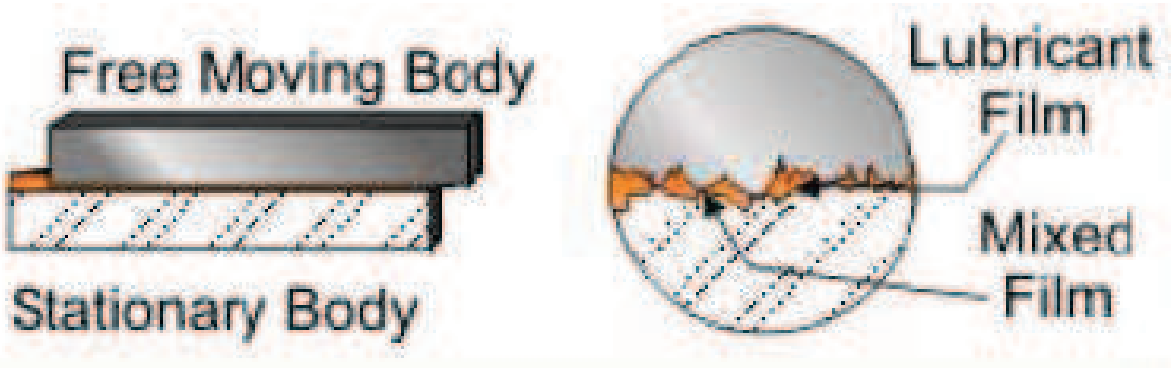
Elastohydrodynamic Lubrication

Elastohydrodynamic lubrication - the opposing surfaces are separated but there may occur some interaction between the raised solid features (asperities), and there is an elastic deformation on the contacting surface enlarging the load bearing area whereby the viscous resistance of the lubricant becomes capable of supporting the load.



Mixed Lubrication

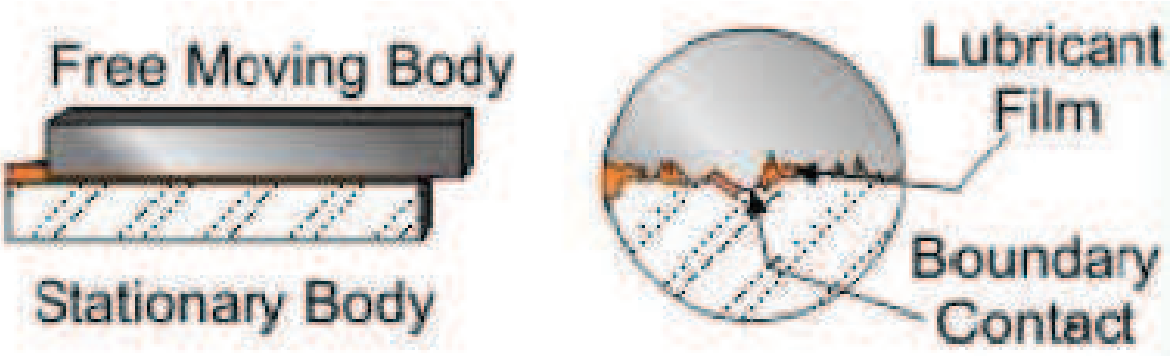
Mixed lubrication – occurs an some contact between the friction surfaces at higher surface points (asperities). Mixed lubrication is the intermediate regime between boundary lubrication and hydrodynamic friction



Boundary Lubrication

Boundary lubrication - the bodies come into contact at their asperities; the heat developed by the local pressures can cause surface damage.

The load is carried by the surface asperities rather than by the lubricant.

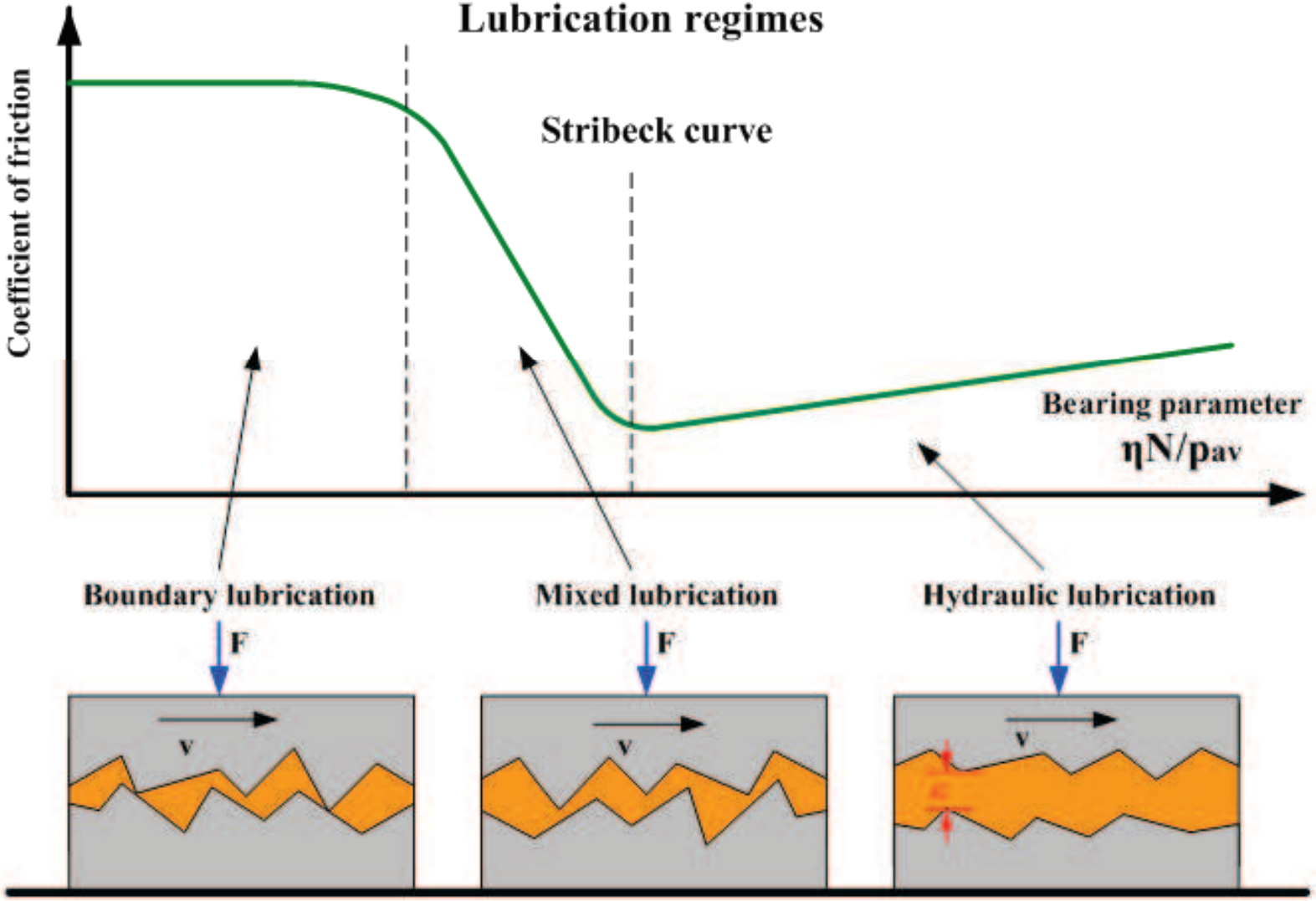


Stribeck Curve

The lubrication regimes are clearly distinguished on the **Stribeck curve** which demonstrates the relationship between the coefficient of friction and the following bearing parameters:

1. η – dynamic viscosity of the lubricant
2. N – rotation velocity
3. p – average pressure

Stribeck Curve



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Bearings

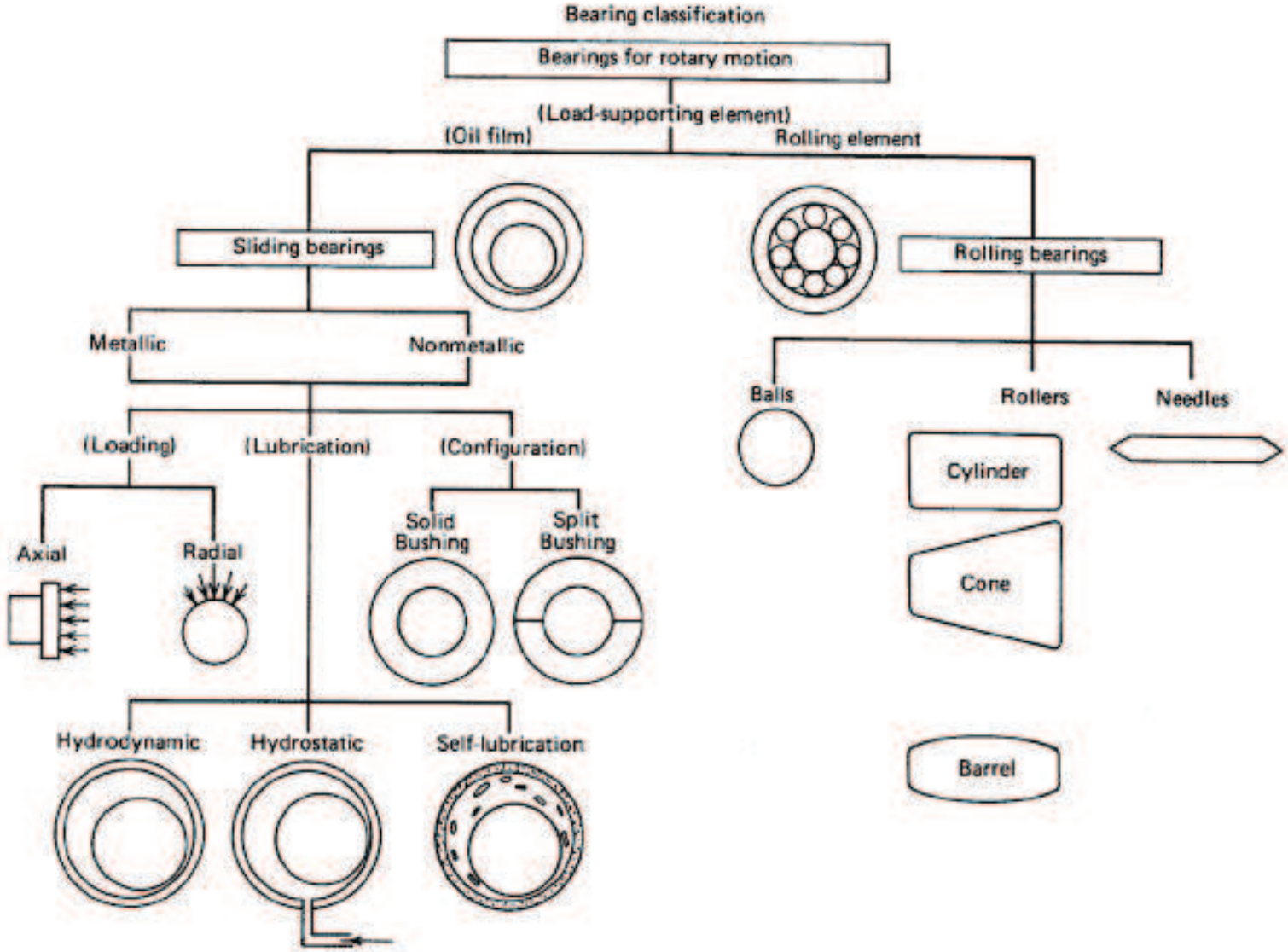
Bearing – permits relative motion between two machine members while minimizing frictional resistance. A bearing consists of an inner and outer member separated either by a thin film of lubricant, or a rolling element.

BEARINGS

Rolling-element bearings

Plain bearings

Bearing Classification



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Plain Bearings

Plain bearing - the simplest type of bearing, comprising just a bearing surface and no rolling elements, e.g a shaft rotating in a hole.

1. Journal bearings - a shaft rotating in a bearing

2. Linear bearings – provides linear motion

3. Thrust bearings -provides a bearing surface for forces acting axial to the shaft

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Plain Bearings Working Principles

The most important working life parameter of plain bearings is the resistance of wear that is dependant of the regime of friction.

Plain bearings must be made from a material that is durable, low friction, low wear to the bearing and shaft, resistant to elevated temperatures and corrosion.

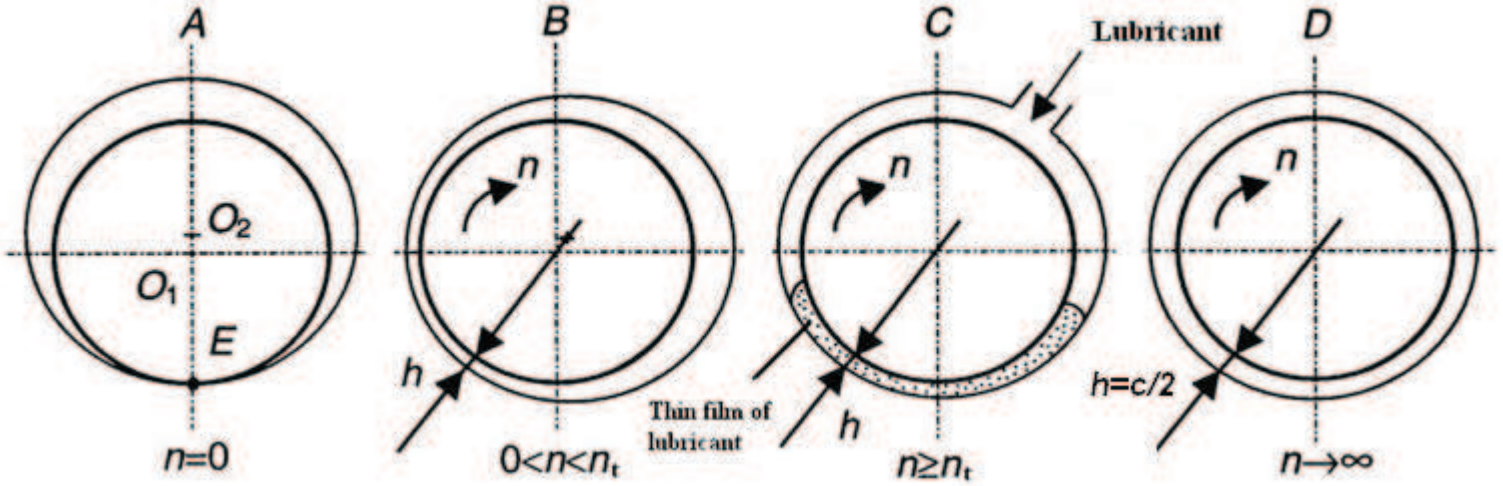
Regimes of Friction

A. The moment before machine initiation = dry friction at point E (zone I)

B. The velocity increases (n↑): dry friction ⟶ boundary lubricaction ⟶ mixed lubrication (zone II on Stribeck graph)

C. At transition frequency (n_t) lubrication film raises the shaft from its supporting surface ⟶ fluid friction (zone III on Stribeck graph)

D. If n ↑ further, the centers continue to approaching until they intersect (O_1=O_2) when n⟶∞



Regimes of Friction

Stribeck curve for the previous case:

h – minimal clearance between the shaft and the bearing

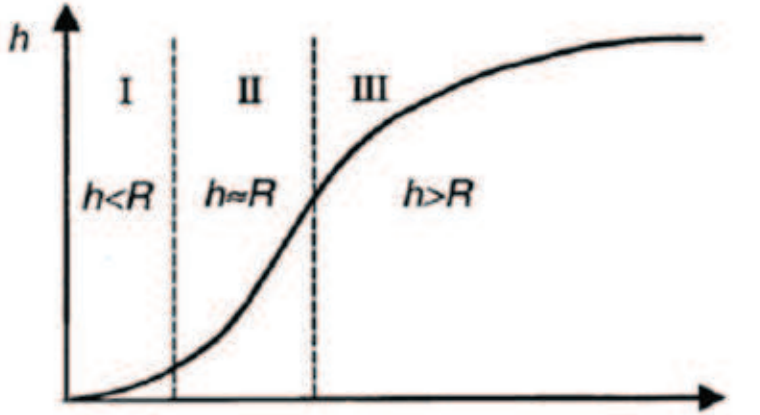
R – height of surface asperities

Sommerfeld number describes the characteristics of a bearing:

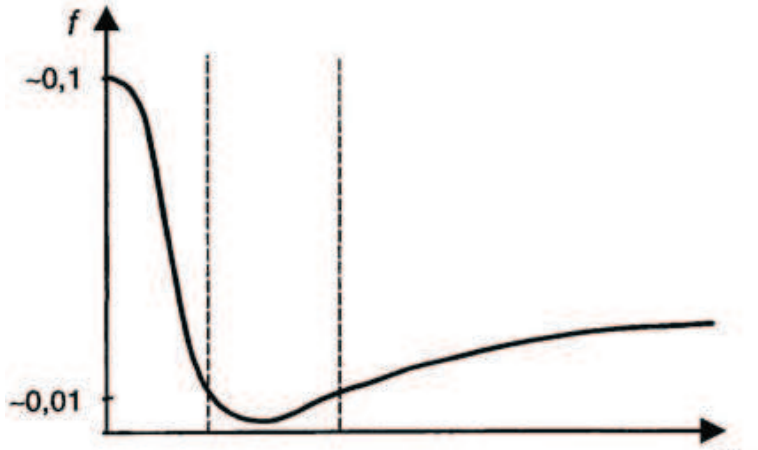
$$S_0 = \left(\frac{r}{c}\right)^2 \frac{\eta n}{P}$$

r – journal radius; c – radial clearance; η – viscosity; n – journal rotation speed (rev/s);

P - load per unit of projected bearing area



Minimal clearance between the shaft and the bearing



Coefficient of friction