Chapter 11 Design of Low Friction Surfaces

Design of Low Friction Surfaces (no lubricant allowed)

- Consider the task of creating low friction surfaces for sliding applications.

  FR_1 = Support the normal load

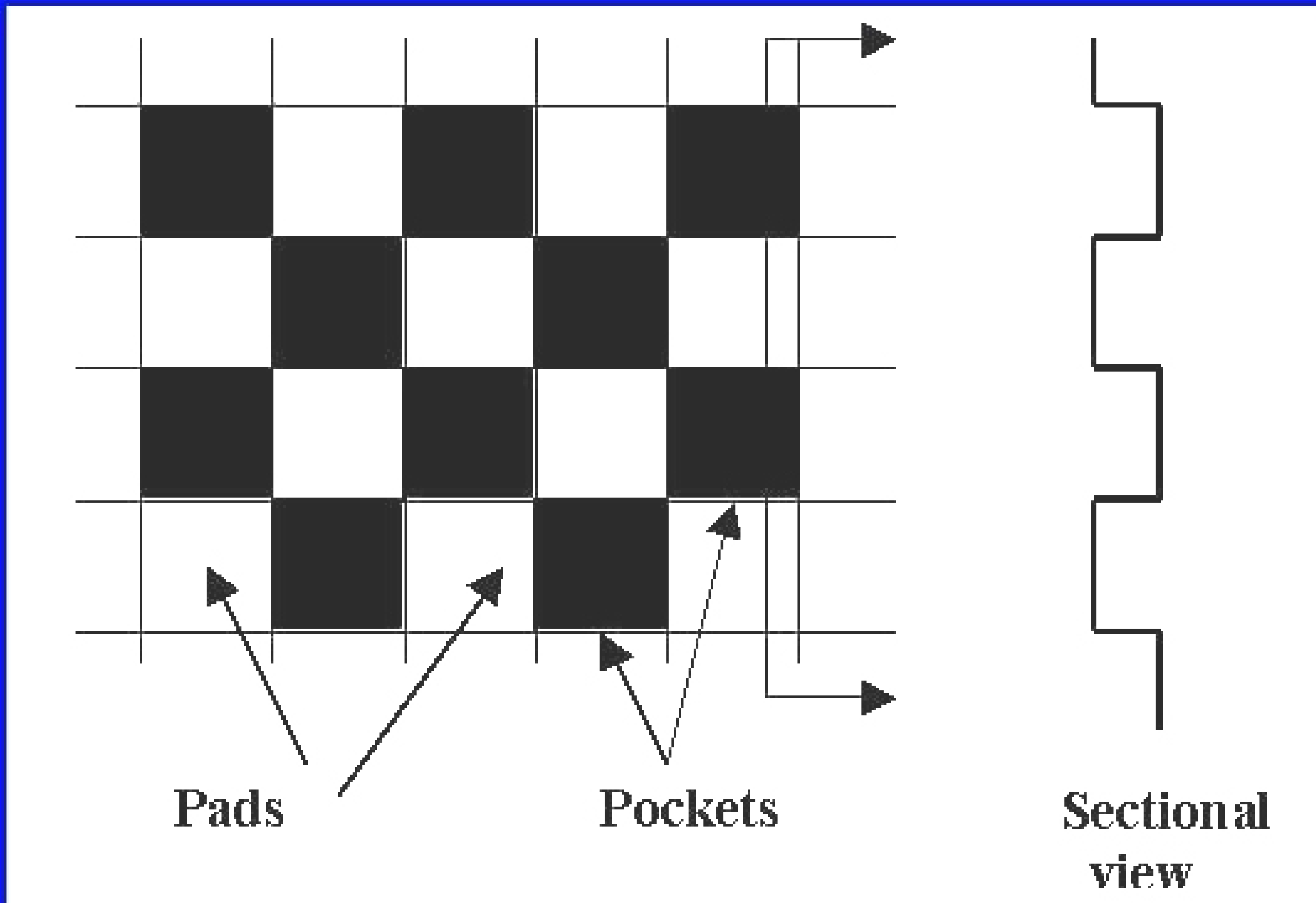
  FR_2 = Prevent particle generation

  FR_3 = Prevent particle agglomeration

  FR_4 = Remove wear particles from the interface

- The constraint is that lubricants cannot be used.

Design of Low Friction Surfaces



Design of Low Friction Surfaces

- The design parameters (DPs) for the undulated surface that can satisfy the FRs are as follows:

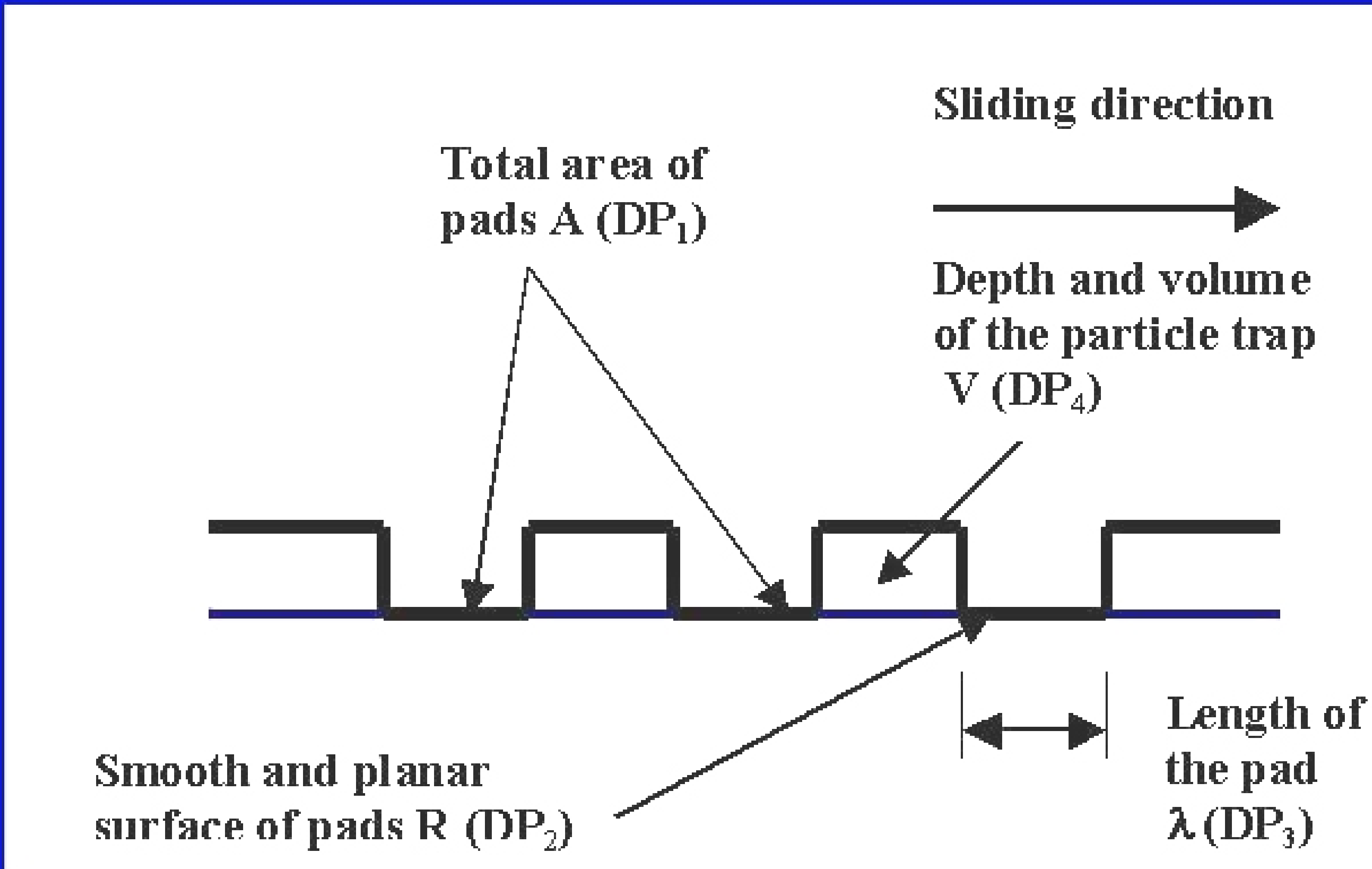
  DP_1 = Total contact area of the pad, A

  DP_2 = Roughness of the planar surface of pads, R

  DP_3 = Length of the pad in the sliding direction, λ

  DP_4 = Volume and depth of the pocket for wear particles, V

Design of Low Friction Surfaces



Design Equation for Undulated Surface

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \\ FR_4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & x & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \\ DP_4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & x & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} A \\ R \\ \lambda \\ V \end{Bmatrix}$$

Lubricated Low Friction Surface

FR_1 = Support the normal load
FR_2 = Prevent particle generation
FR_3 = Prevent particle agglomeration
FR_4 = Remove wear particles from the interface

Design of Lubricated Low Friction Surfaces

- FRs are

  FR_1 = Support the normal load

  FR_2 = Prevent particle generation

  FR_3 = Prevent particle agglomeration

  FR_4 = Remove wear particles from the interface

Design of Lubricated Low Friction Surfaces

- DPs are

  DP_1 = Total contact area of the pad, A

  DP_2 = Roughness of the planar surface of pads, R

  DP_3 = Boundary lubricant, Lub

  DP_4 = Volume and depth of the pocket for wear particles, V

Geometrically Constrained System

Material	Mean Roughness Ra (μm)	Rockwell Hardness
M50 Ball	0.050	C-Scale 62
304 Stainless Steel Blocks	0.263	B-Scale 80
MoS_2 coated Blocks	0.361	-
AFSL 200 coated Blocks	0.388	-

Geometrically Constrained System

Surface properties of shafts and bushings

Material	Mean Roughness Ra(μm)	Hardness (Rockwell)
Hardened Steel Bushing	0.255	C-cale 68
304 Stainless steel Shaft	0.263	B-Scale 80
MoS2 coated shafts	0.361	-

Geometrically Constrained System

Steady state friction coefficients of uncoated and coated surfaces obtained from pin-on-disk tests. Normal Load = 50g

Specimen	Smooth	Undulated
Uncoated	0.7	0.18
MoS_2 Coated	0.24	0.18
AFSL 200 Coated	0.125	0.11

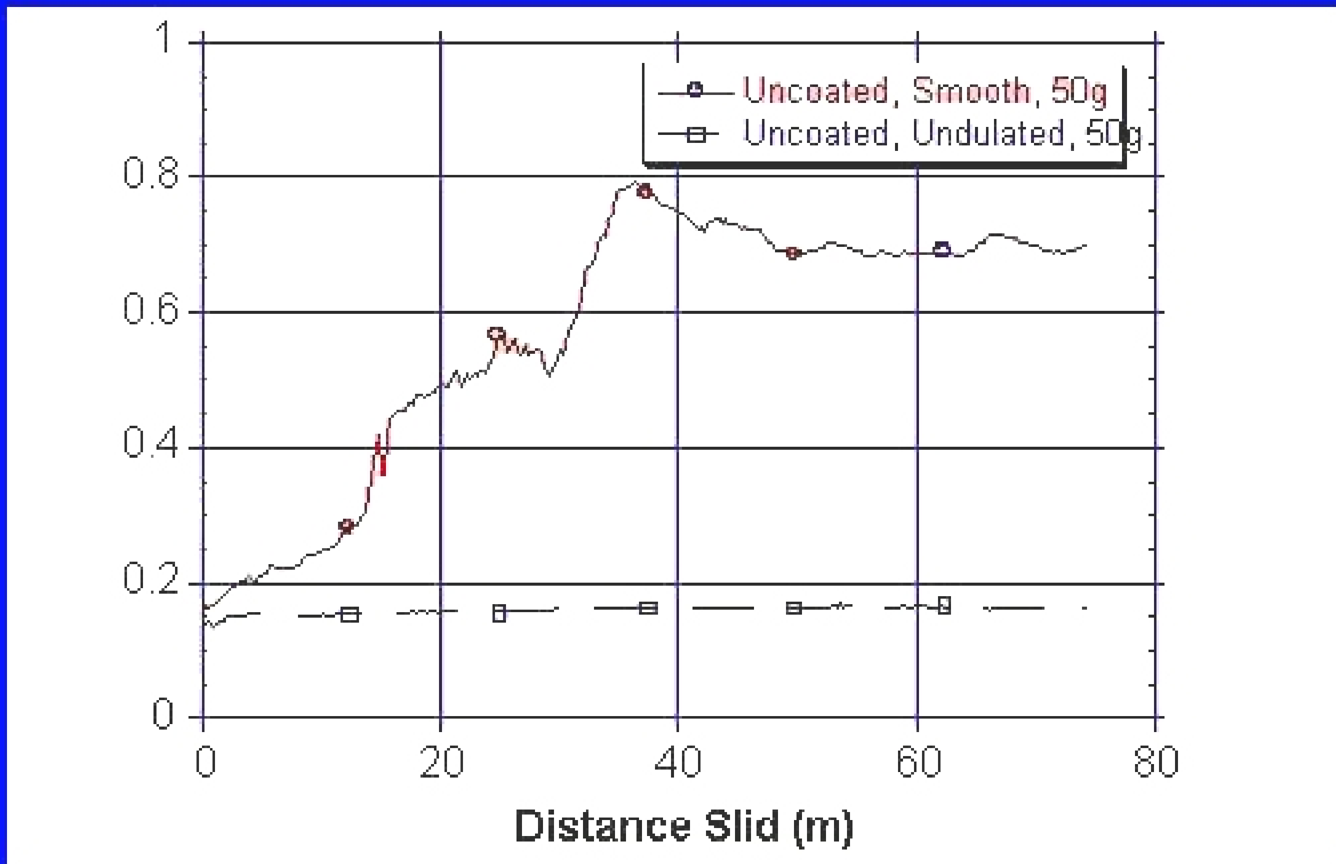
Geometrically Constrained System

Steady state friction coefficients of uncoated and coated surfaces obtained from pin-on-disk tests. Normal Load = 200g

Specimen	Smooth	Undulated
Uncoated	0.75	0.42
MoS_2 Coated	0.175	0.125
AFSL 200 Coated	0.100	0.075

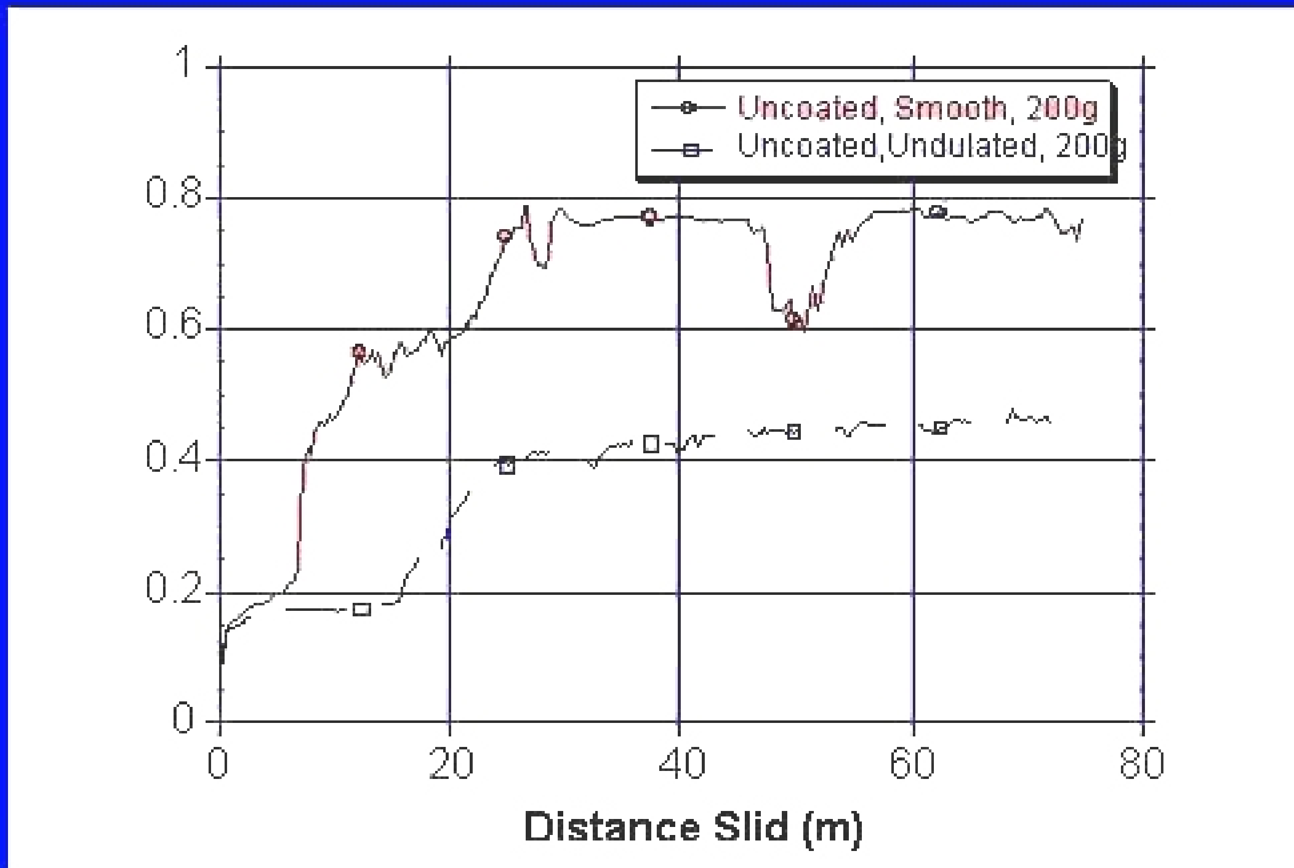
Geometrically Constrained System

Pin-on-disk experiment with uncoated stainless steel 304 sliding against M50 steel ball under normal load of 50 g.



Geometrically Constrained System

Pin-on-disk experiment with uncoated stainless steel 304 sliding against M50 steel ball under normal load of 200 g.



Microscale Undulated Surfaces

Microstructured surface of silicon. The textured dimension of the undulation -– the width of the line -- of (a) and (b) is 5 μm. The corresponding dimension of (c) and (d) is 50 μm. [Cha and Kim, 2000]

Figures removed for copyright reasons.

Source: Kim, D. E., K. H. Cha, and I. H. Sung. "Design of Surface Micro-structures for Friction Control in Micro-systems Applications." *Annals of the CIRP* 51, no. 1 (2002): 495-498.

Microscale Undulated Surfaces

The worn surface of Si3N4 coated flat surface and the undulated surface. The undulated surface did not wear much. Wear particles were in the pocket. [Cha and Kim, 2000]

Figures removed for copyright reasons.

Source: Kim, D. E., K. H. Cha, and I. H. Sung. "Design of Surface Micro-structures for Friction Control in Micro-systems Applications." *Annals of the CIRP* 51, no. 1 (2002): 495-498.

Microscale Undulated Surfaces

The friction coefficients of aluminum coated flat surface and microscale textured undulated surfaces at two different loads. The one on the left is for 1 gf and the one on right is for 5 gf. [Cha and Kim, 2000]

Figures removed for copyright reasons.

Source: Kim, D. E., K. H. Cha, and I. H. Sung. "Design of Surface Micro-structures for Friction Control in Micro-systems Applications." *Annals of the CIRP* 51, no. 1 (2002): 495-498.

Conventional Electrical Connectors

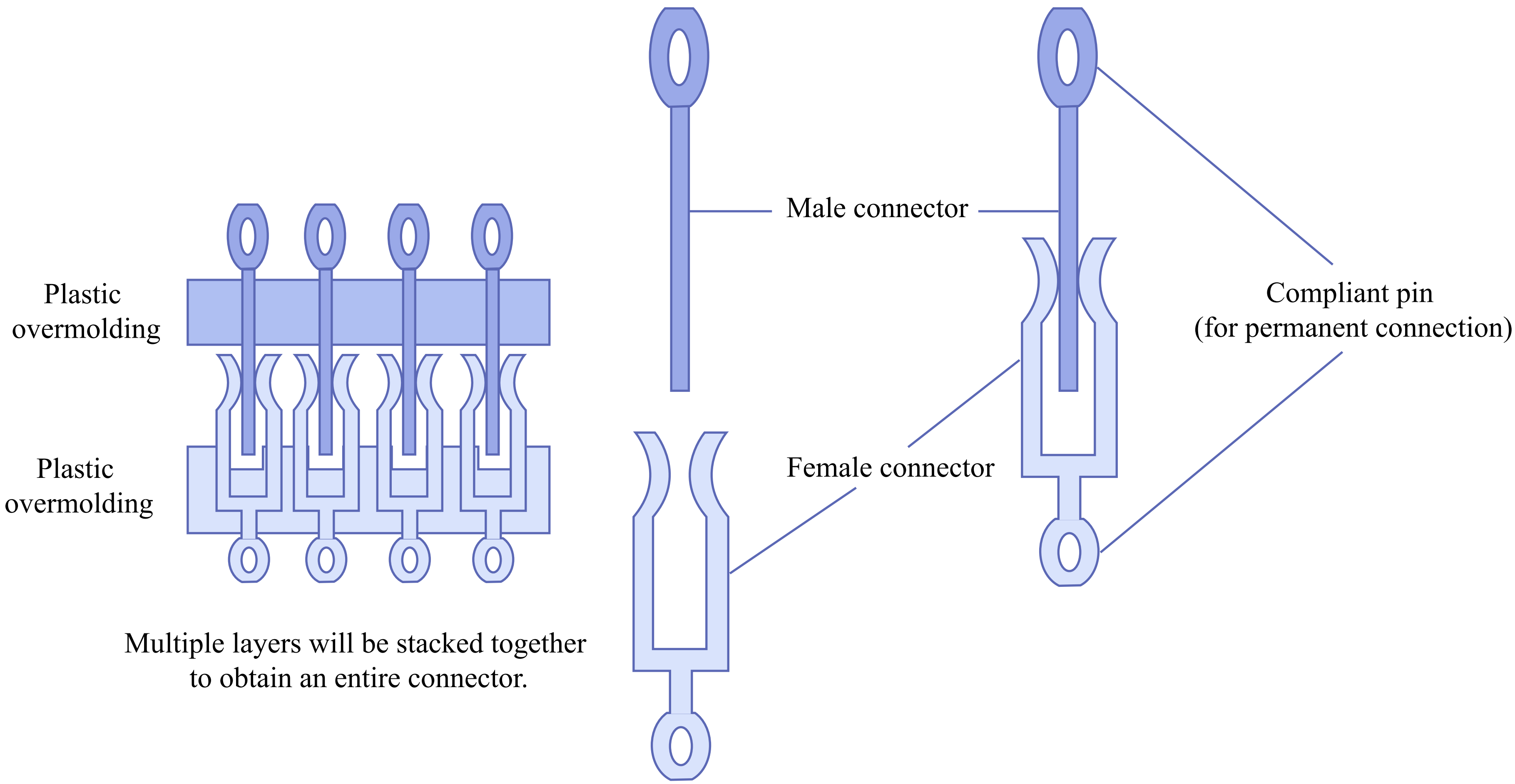


Figure by MIT OCW.

FRs of an Electrical Connector

FR1 = Mechanically connect and disconnect electrical terminals

FR2 = Control contact resistance (should be less than 20mΩ)

FR3 = Prevent the cross-talk (i.e., interference) between the connections

Subject to the following constraints (Cs):

C1 = Low cost

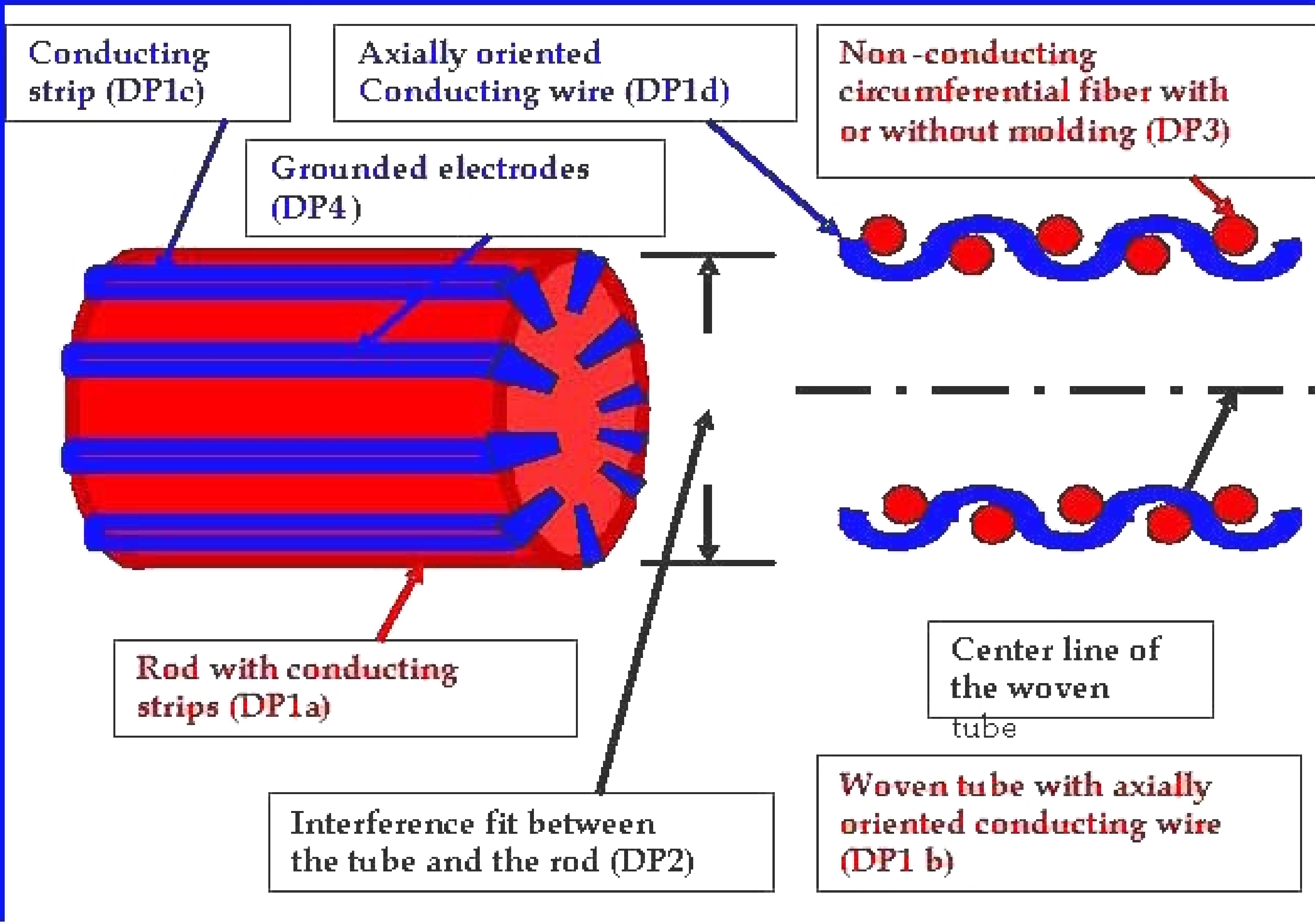
C2 = Ease of use

C3 = Long life (> million cycles)

C4 = Maximum temperature rise of 30 ^{o}C

C5 = Low insertion force

Physical Embodiment of an Electrical Connector



DPs of an Electrical Connector

DP1 = Cylindrical assembly of the woven tube and the pin

DP2 = Locally compliant electric contact

DP3 = Number of conducting wires

Decomposition of FR1 (Mechanically connect and disconnect electrical terminals) and DP1 (Cylindrical assembly of the woven tube and the pin)

FR11 = Align the rod axially inside the tube

FR12 = Locate the axial position of the rod in the tube

FR13 = Guide the pin

DP11 = Long aspect ratio of the rod and the tube

DP12 = Snap fit

DP13 = Tapered tip of the pin

Decomposition of FR2 (Control contact resistance to be less than 20mΩ) and DP2 (Locally compliant electric contact)

FR21 = Prevent oxidation of the conductor

FR22 = Remove wear particles

FR23 = Control line tension/deflection of the non-conducting fiber

DP21 = Gold plated metal surface

DP22 = Space created in the crevices between fibers

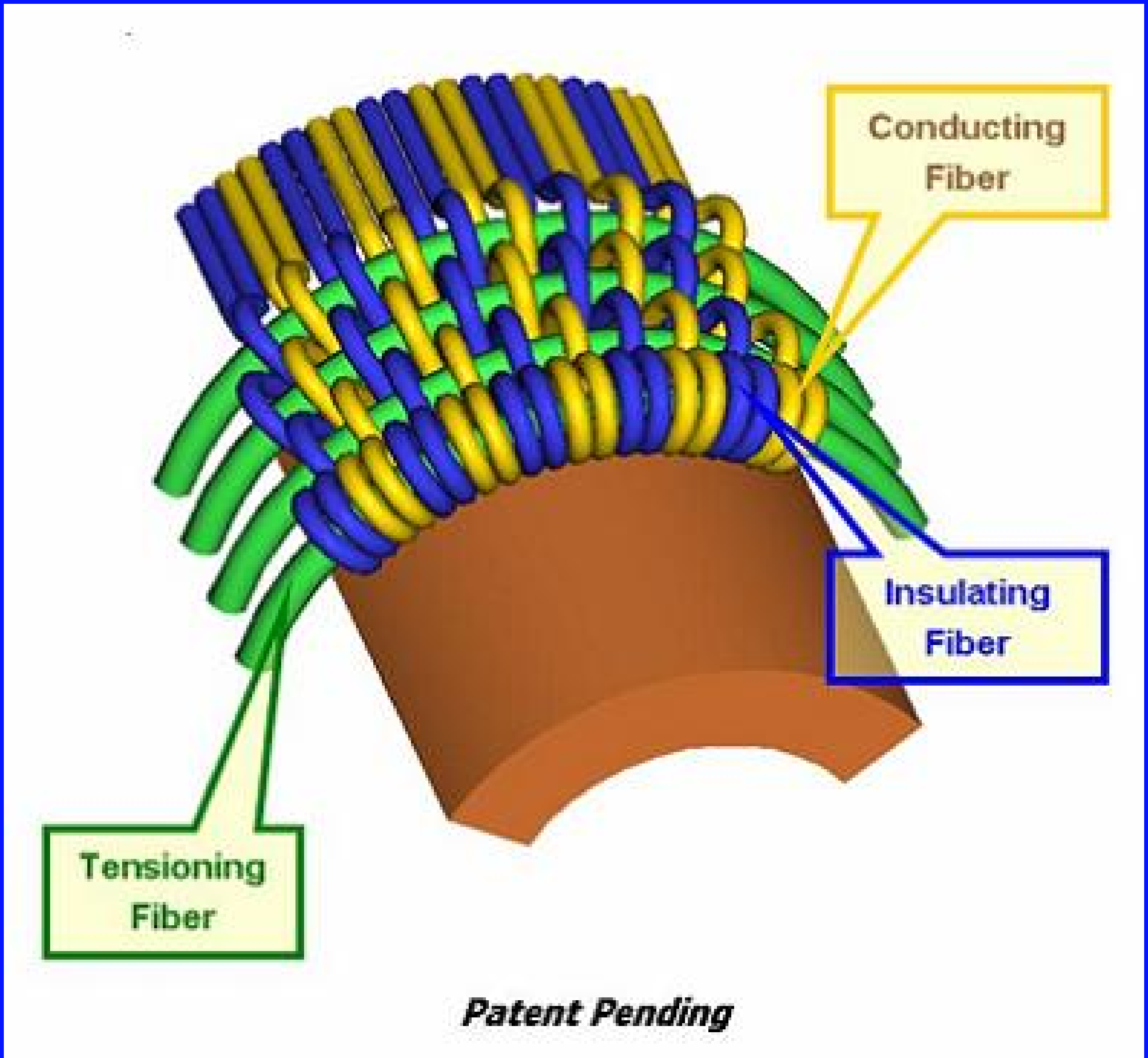
DP23 = Spring

Design Matrix

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X00 \\ XX0 \\ 0XX \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}$$

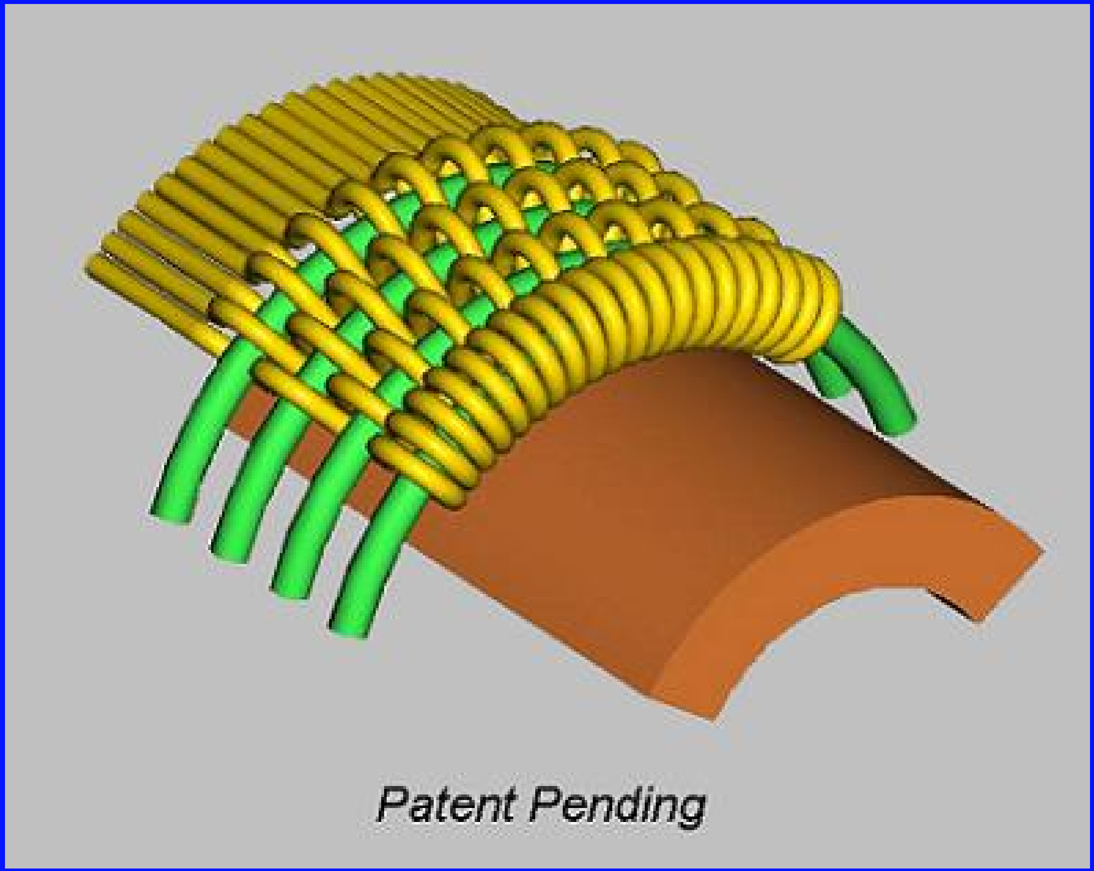
Tribotek Electrical Connectors

(Courtesy of Tribotek, Inc. Used with permission.)



Tribotek Electrical Connectors

(Courtesy of Tribotek, Inc. Used with permission.)



Performance of "Woven" Power Connectors

- Power density => 200% of conventional connectors
- Insertion force => less than 5% of conventional connectors
- Electric contact resistance = 5 m ohms
- Manufacturing cost
- Capital Investment