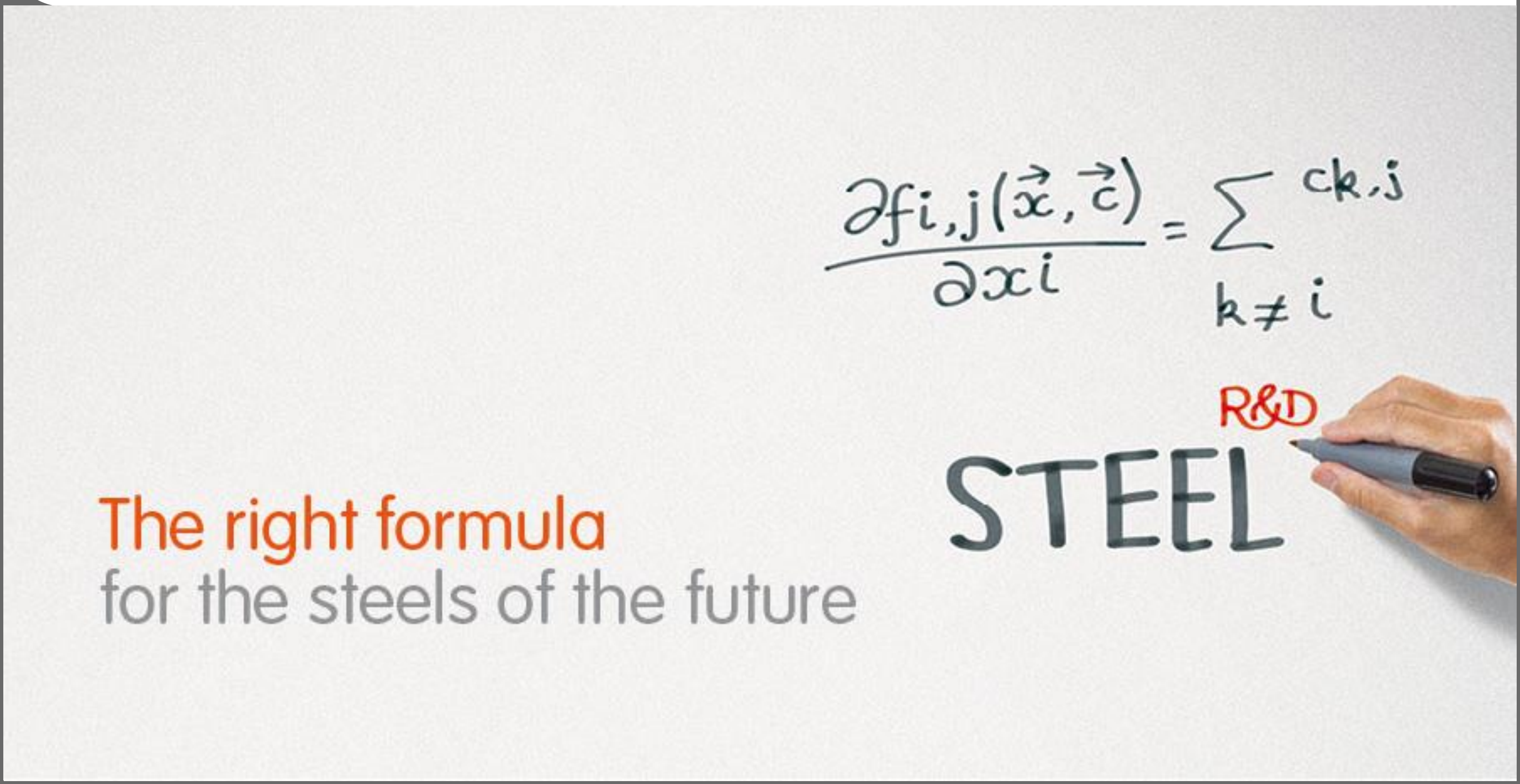
Global Research and Development

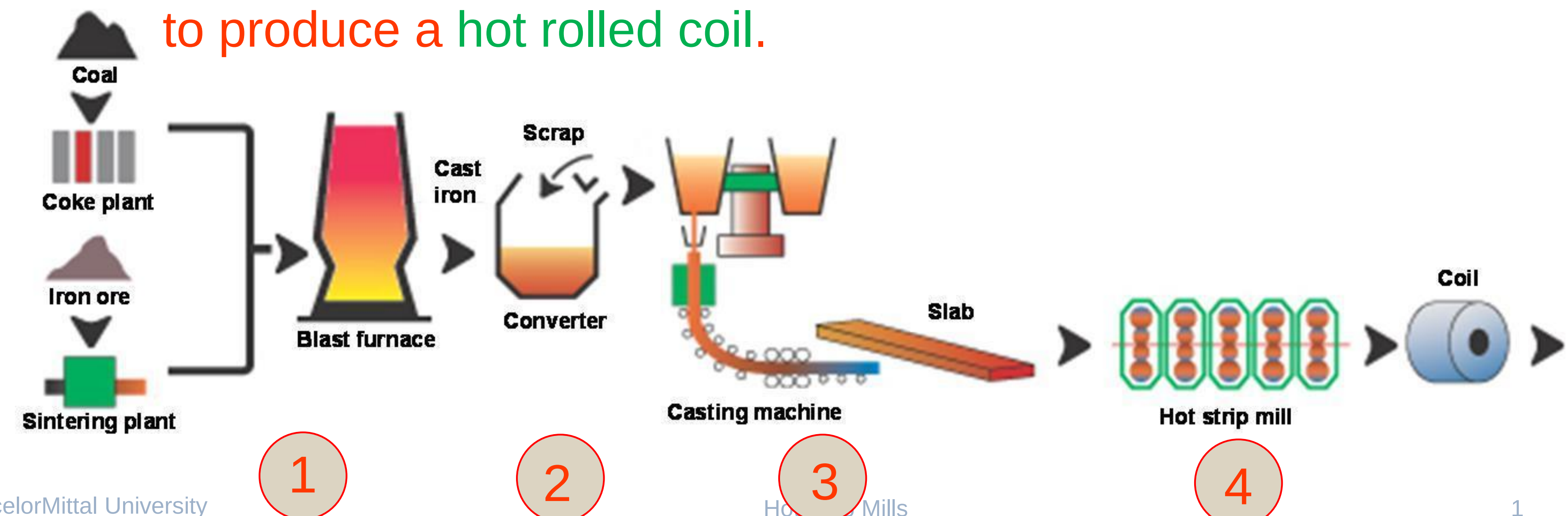
ArcelorMittal

Industrial applications based on friction



Integrated steel production route
Primary

1. Hot metal is obtained in the blast furnace from the reduction of the iron ore by the coke
2. Steel is obtained in the converter where the high carbon level is removed from the cast iron
3. Liquid steel is solidified as a slab in the casting machine
4. Slab thickness and width are reduced in the hot strip mill while microstructure and surface aspect are controlled, to produce a hot rolled coil.



Hot Strip Mills in ArcelorMittal

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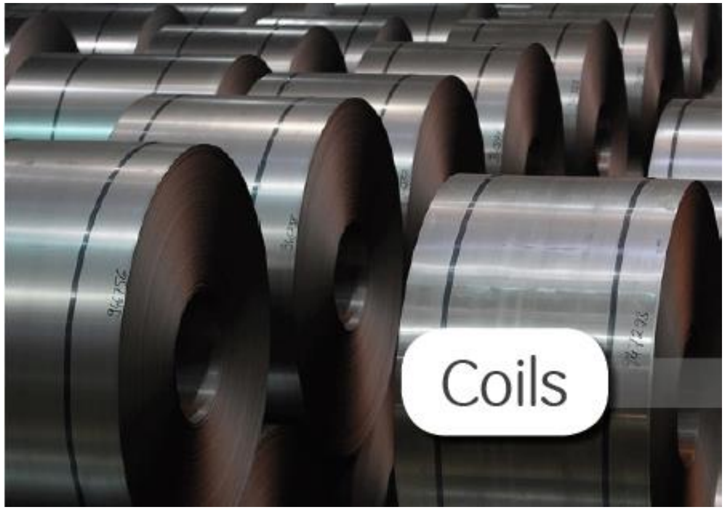
ArcelorMittal: 19 Flat **carbon** mills

In Hot Strip Mill, slabs are transformed into coils



Thickness: 220-260 mm → 1.8-25 mm

Length: 5-15 m → 400-1500 mm

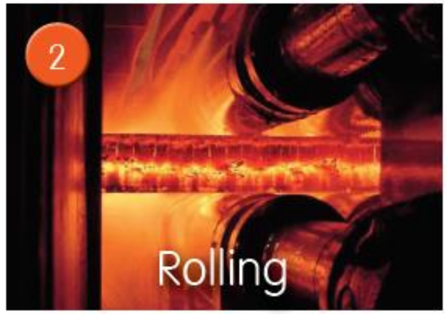
Width: 800-2200 mm

Weight: 20-35 t (yield : ~97%)

Why do we hot roll?

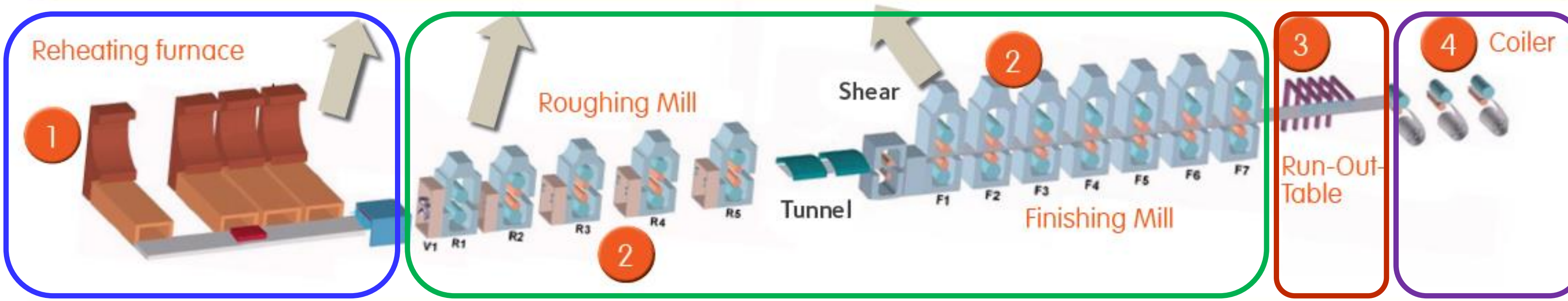
- **What are the main objectives of the Hot Strip Mill process?**
  - To reduce the product thickness and width
  - To obtain the surface quality and the mechanical properties required by the customer
- **Why hot rolling but not only cold rolling?**
  - Easier: hot rolling is done over phase transformation temperature (Curie temperature ~725ºC)
  - Recrystallization phenomenon is active → almost no work-hardening and enable very high thickness reduction (up to ~100 times)

The 4 main steps of Hot Strip Mill process



1. Reheating: Slab, coming from continuous casting, is heated during 3h up to about 1200°C.

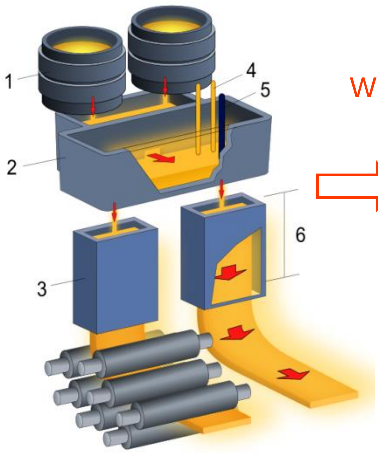
2. Rolling: After descaling, slab is rolled in two steps: roughing and finishing mills to achieve desired width and thickness. Its temperature decreases to 800-900°C.



3. Cooling: On run-out table, strip is cooled down to 550-750°C through a controlled scheme to achieve the desired microstructure and mechanical properties.

4. Coiling: Strip is finally wound into a coil to be easily delivered to customers.

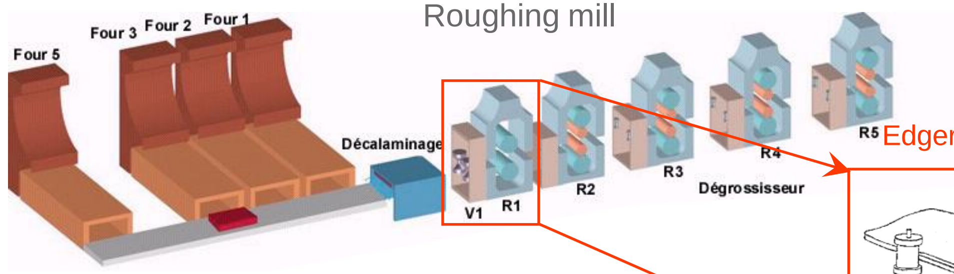
Width management



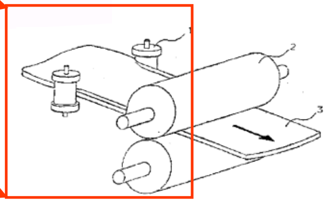
Width ranges

800, 1200…
2000mm

Roughing mill

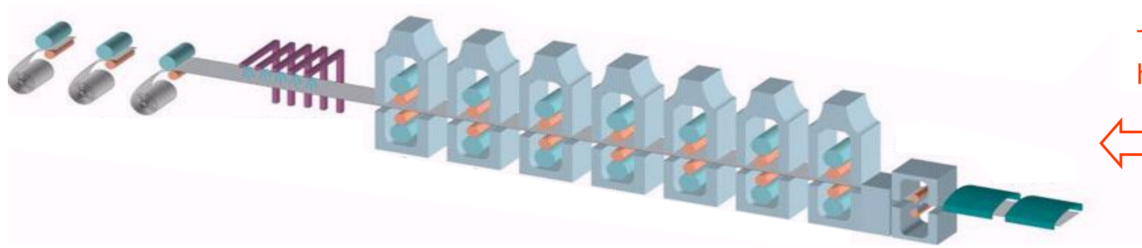


Edger



Target
homogeneous width

Finishing Mill



Final Hot Rolled
Width

Finishing Mill

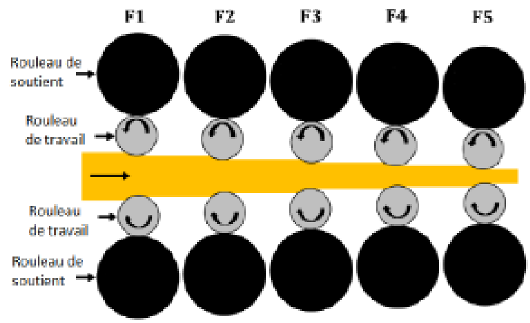
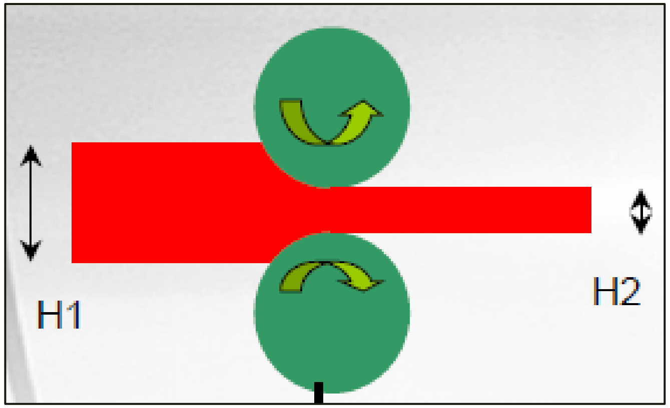


FIG. 6: Finisseur à cinq cages



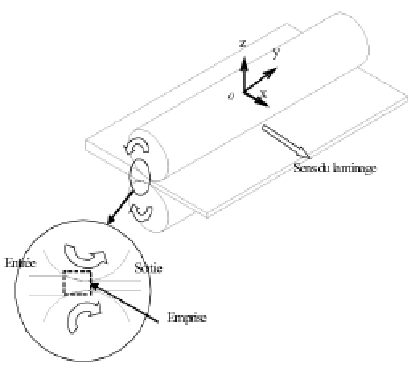
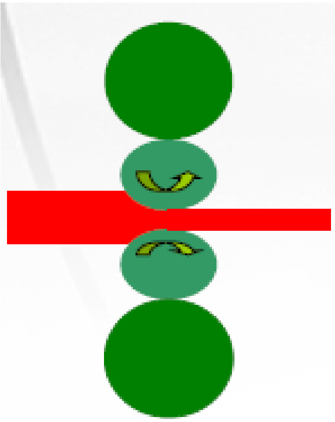
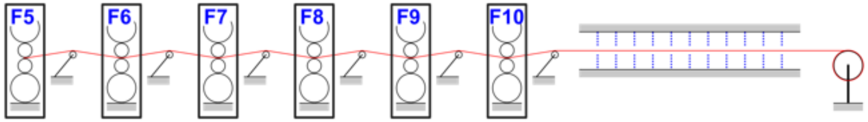


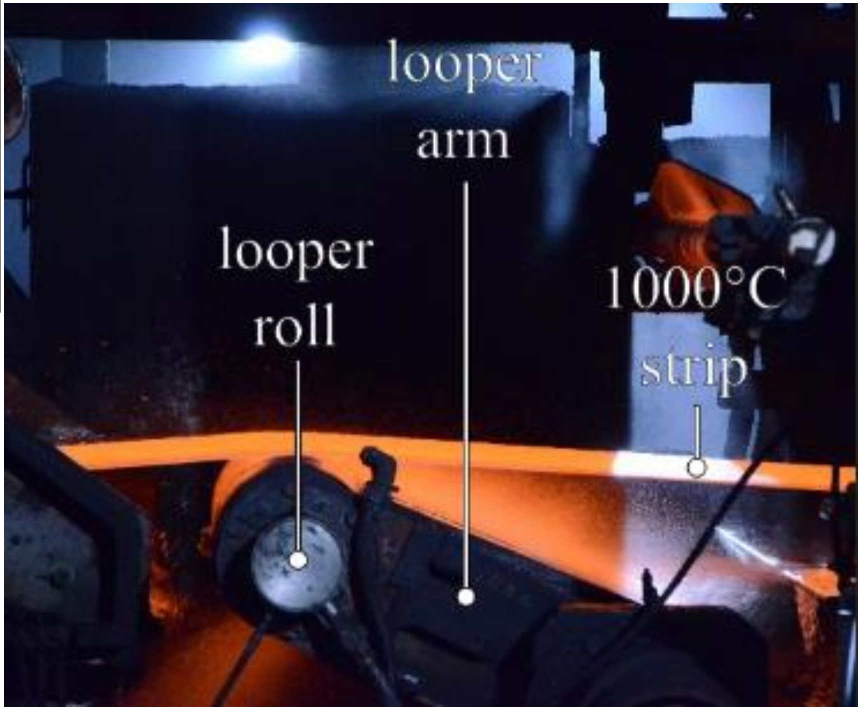
FIG. 7: L'emprise du cylindre



The stand is deformed during rolling

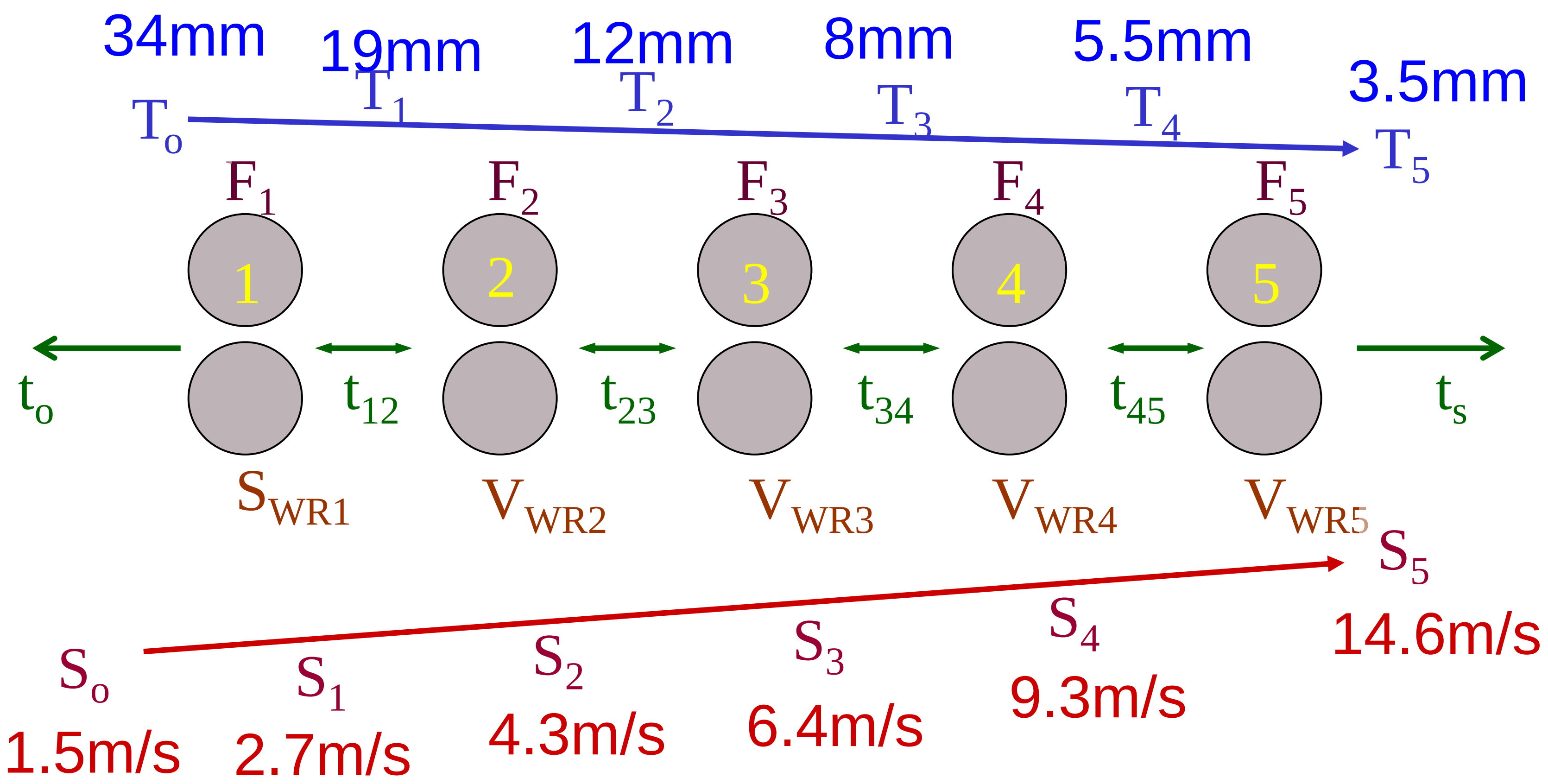
Finishing Mill



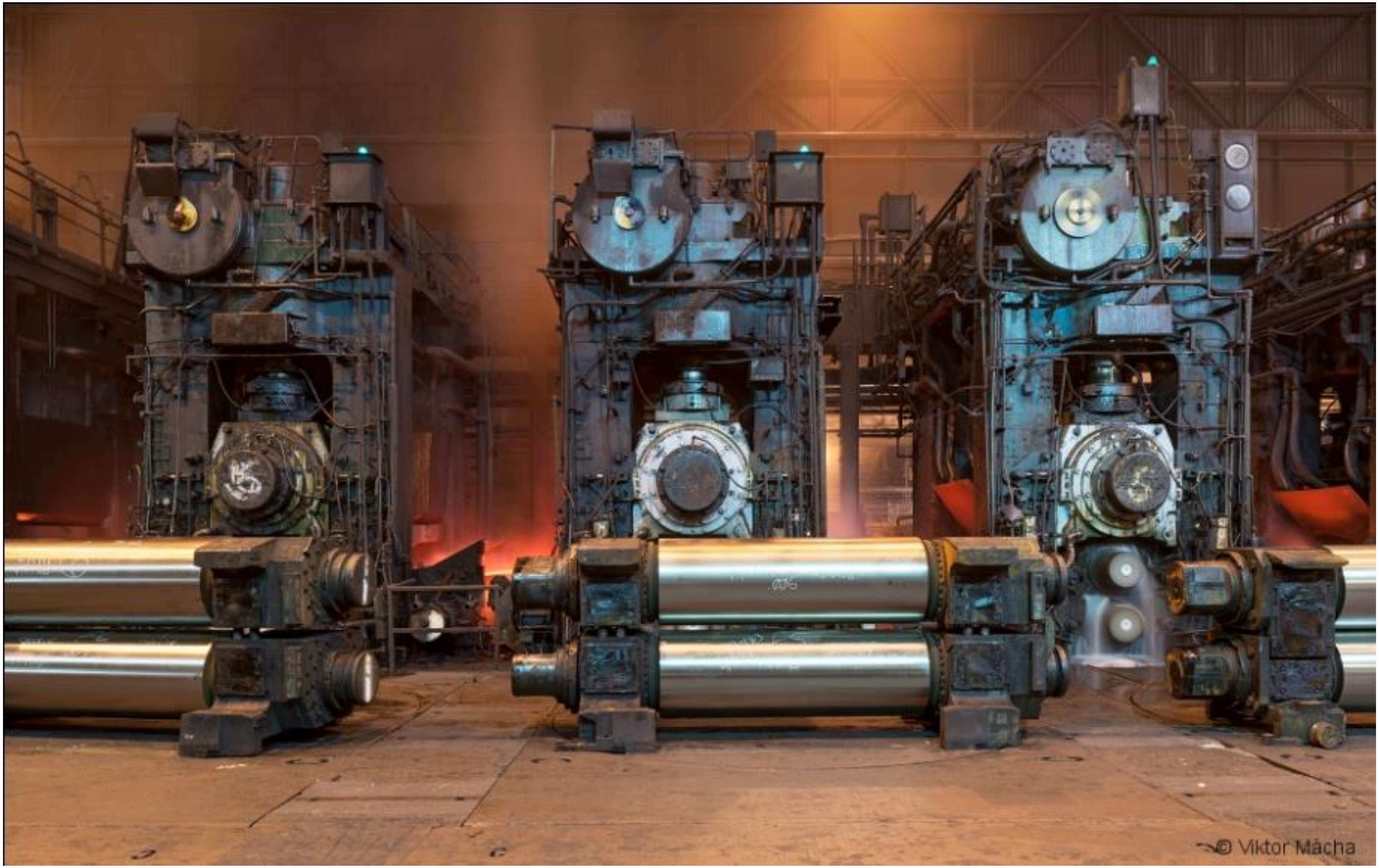


Finishing mill

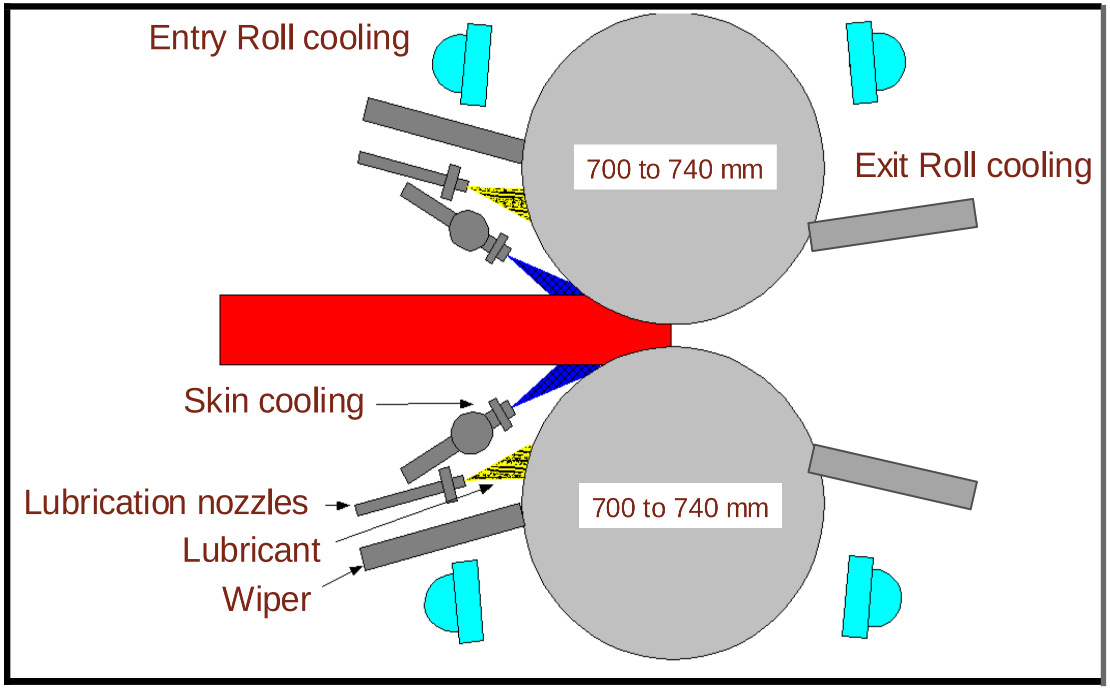
Example of a finishing mill rolling scheme



Finishing mill



Work-rolls



- **Why is it important to cool down the work roll?**
- **Why is it important to lubricate the bite?**
- **Work-rolls may be smaller or bigger in diameter: why?**

Work-rolls

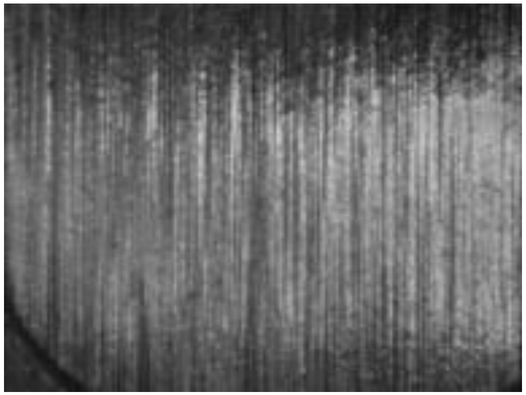
- **Why is it important to cool down the work-roll?**
  - To decrease the oxidation of the work-roll surface
  - To decrease the thermo-mechanical fatigue due to the contact with the hot strip

- **Why is it important to lubricate the bite?**
  - Work-roll surface quality (protection from corrosion)
  - Decrease the roll-bite friction → decrease forces and save energy

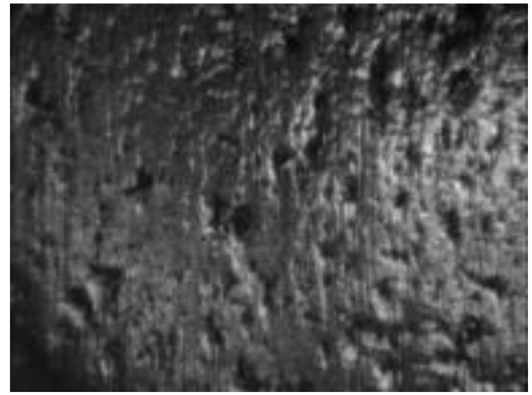
- **Work-rolls may be smaller or bigger in diameter: why?**
  - Threading ability (the bigger the roll the easier) vs. roll forces

Work-rolls surface & strip surface quality

Initial roll roughness



Degraded roll surface



Rolled-in scale

Slight defect

Average defect

Strong defect

Objectives

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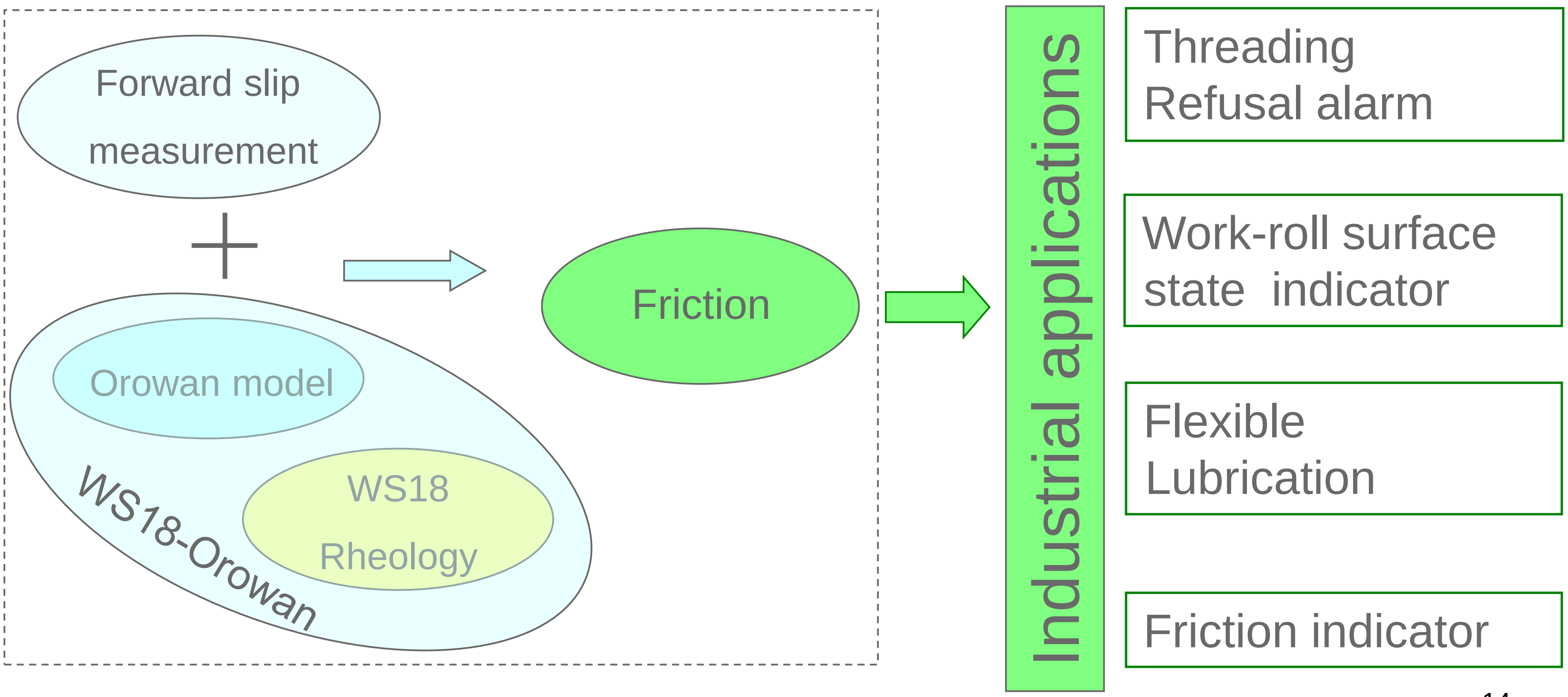
- To develop, based on online friction coefficient calculation:
  - Work-roll degradation indicator
  - Threading refusal prediction and prevention system
  - lubrication efficiency indicator and recommendation for change in preset of lubrication
  - Preset model for roll force, forward slip and torque



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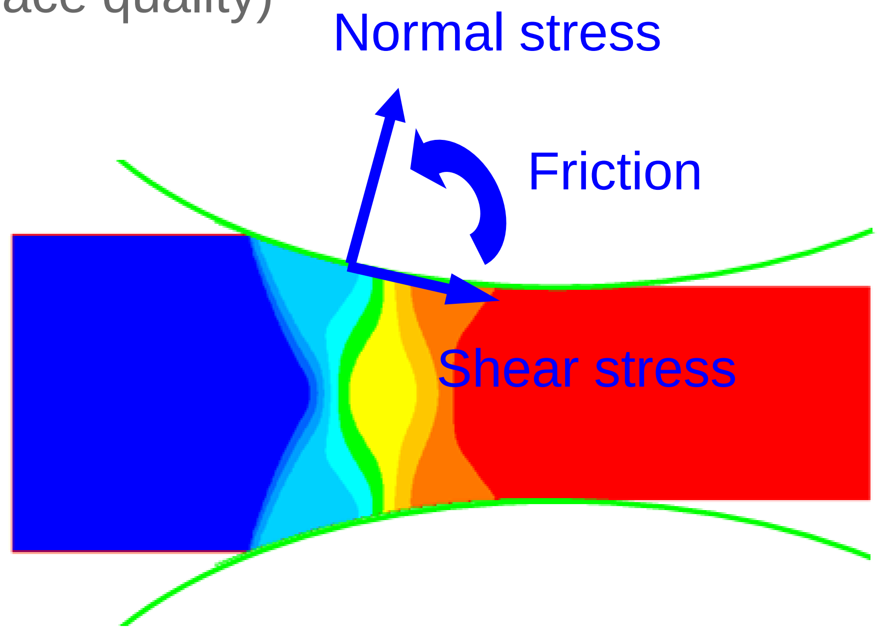
Role of friction in rolling

- Why mastering the friction of roll-strip contact?
  - Surface defects
  - Roll consumption (wear and surface quality)
  - Rolling capability & energy



- How to master the contact friction?
  - Forward slip measurement
  - Back-calculation model of friction based on forward slip

Rolling model OROWAN

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Orowan is a computer implementation of the rolling force model with the same name. It is written in C++ and can generate a library for PC (dll or executable) using the Visual Studio development environment. Model is compatible with other C++ compilers (VMS, Linux).

Model includes the following 2 functions:

DirectCalculation : to determine rolling force and forward slip

Te_{entry} , Te_{exit} →
Th_{entry} , Th_{exit} →
Dia_{WR} →
μ ; σ_0 →

Direct calculation → fs, F

BackCalculation : to determine friction and rheology

The inversion model looks for the values of yield stress and friction level which give a rolling force and a forward slip corresponding to the measurement.

Te_{entry} , Te_{exit} →
Th_{entry} , Th_{exit} →
Dia_{WR} →
F ; fs →

Back calculation → μ ; σ_0

Rolling model OROWAN

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Limits are fixed on inputs/outputs values (adjustable in function of plants):

Measurement	Unit	Min	Domain			Max	Condition
Entry thickness	mm	1.5	$<$	h_e	$\leq$	75	$h_s < h_e$
Exit thickness	mm	1.5	$\leq$	h_s	$<$	75	
Draft	%	1	$<$	reduction	$<$	60	-
Entry tension	MPa	0	$\leq$	T_e	$\leq$	50	-
Exit tension	MPa	0	$\leq$	T_s	$\leq$	50	-
Working roll diameter	mm	500	$\leq$	WR	$\leq$	1500	-
Young modulus (WR)	MPa	120000	$<$	youngWR	$<$	250000	-
Friction coefficient	-	0.05	$<$	mu	$<$	1	-
Offset yield stress	MPa	0	$<$	offset	-	-	rheological law
Rolling force	t/m	150	$<$	force	$<$	5000	-
Forward slip	%	0	$<$	slip	$\leq$	20	-

Online friction back-calculation is a robust solution

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- **Forward slip measurement:** incremental encoder on looper => allows a good precision of friction.
- **Online calculation model (Orowan)** based on force and forward slip to obtain friction coefficient and strip yield stress.