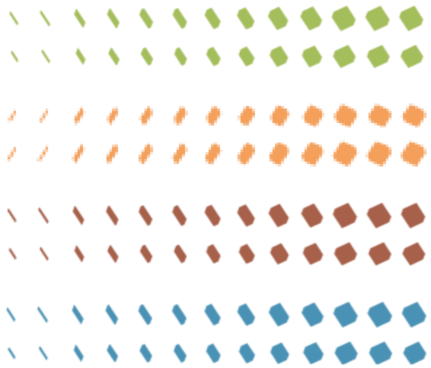


Optimal design of round-oval-round roll pass

Eng. Mostafa Rashad
Rolling mill plant manager
R & D manager

Bar Rolling Process

MKS elmarakbysteel

reinforcing life.

Bar Rolling Process

Intensive energy consumption process

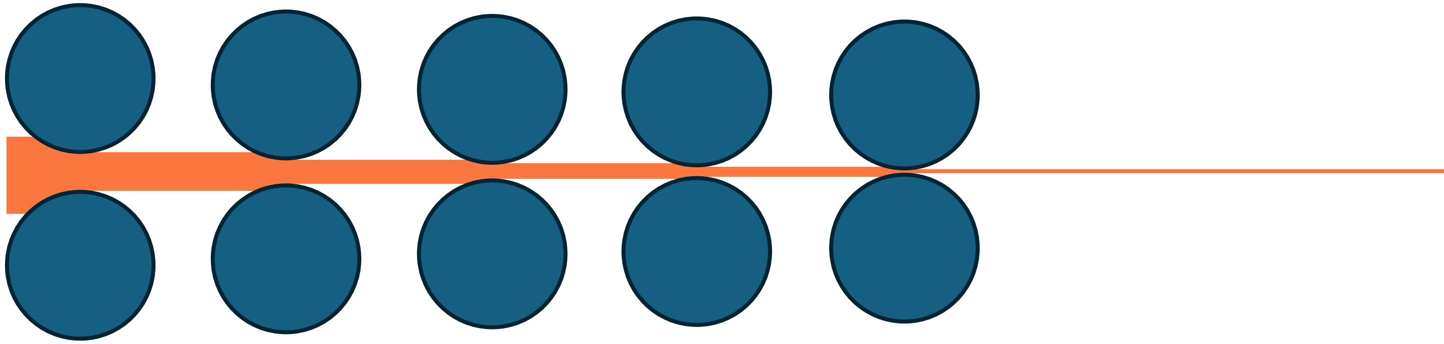
One machine/day

=

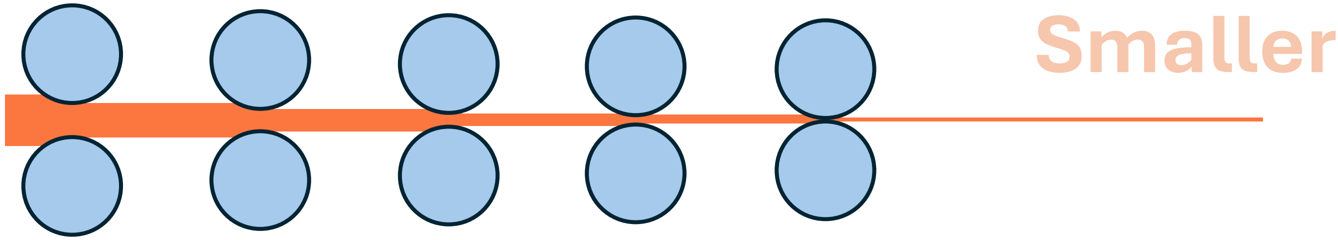
House for 6 months to 1 year

Bar Rolling Process

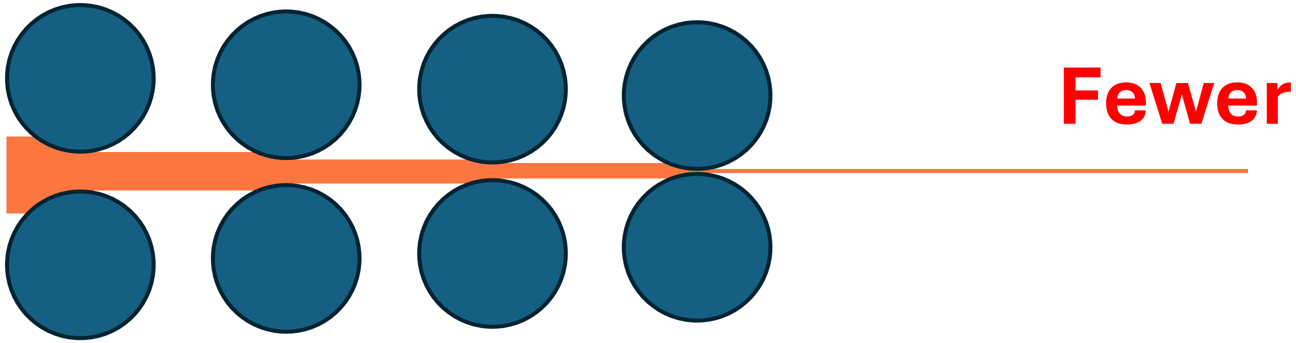
What does the optimum roll pass design mean?



(Optimal minimum rolling torque)
Minimum machine size and energy consumption
Reducing the running cost



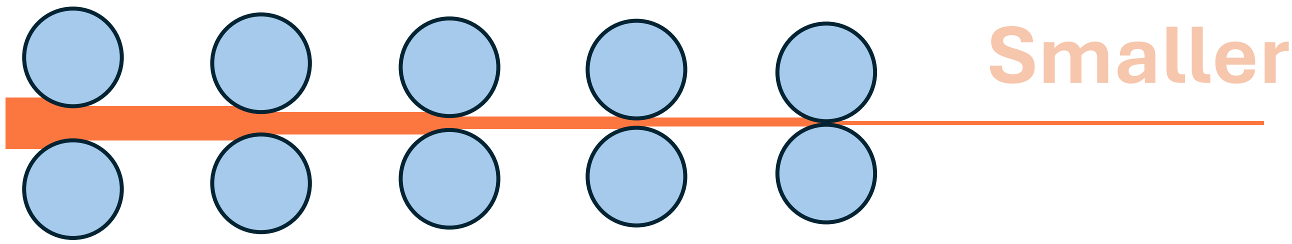
(Optimal maximum area reduction ratio)
Minimum machine quantity
Reducing the CAPEX cost



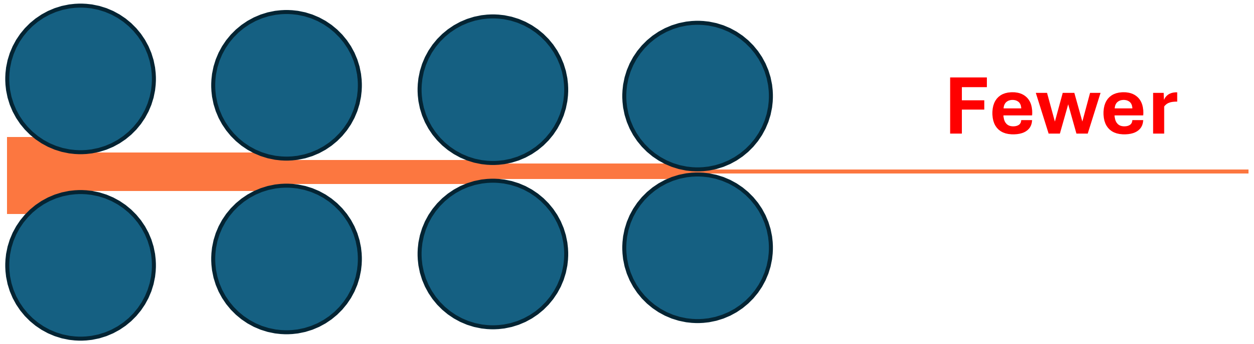
Study Objectives

Optimization Problem Objectives

Minimizing **rolling torque**



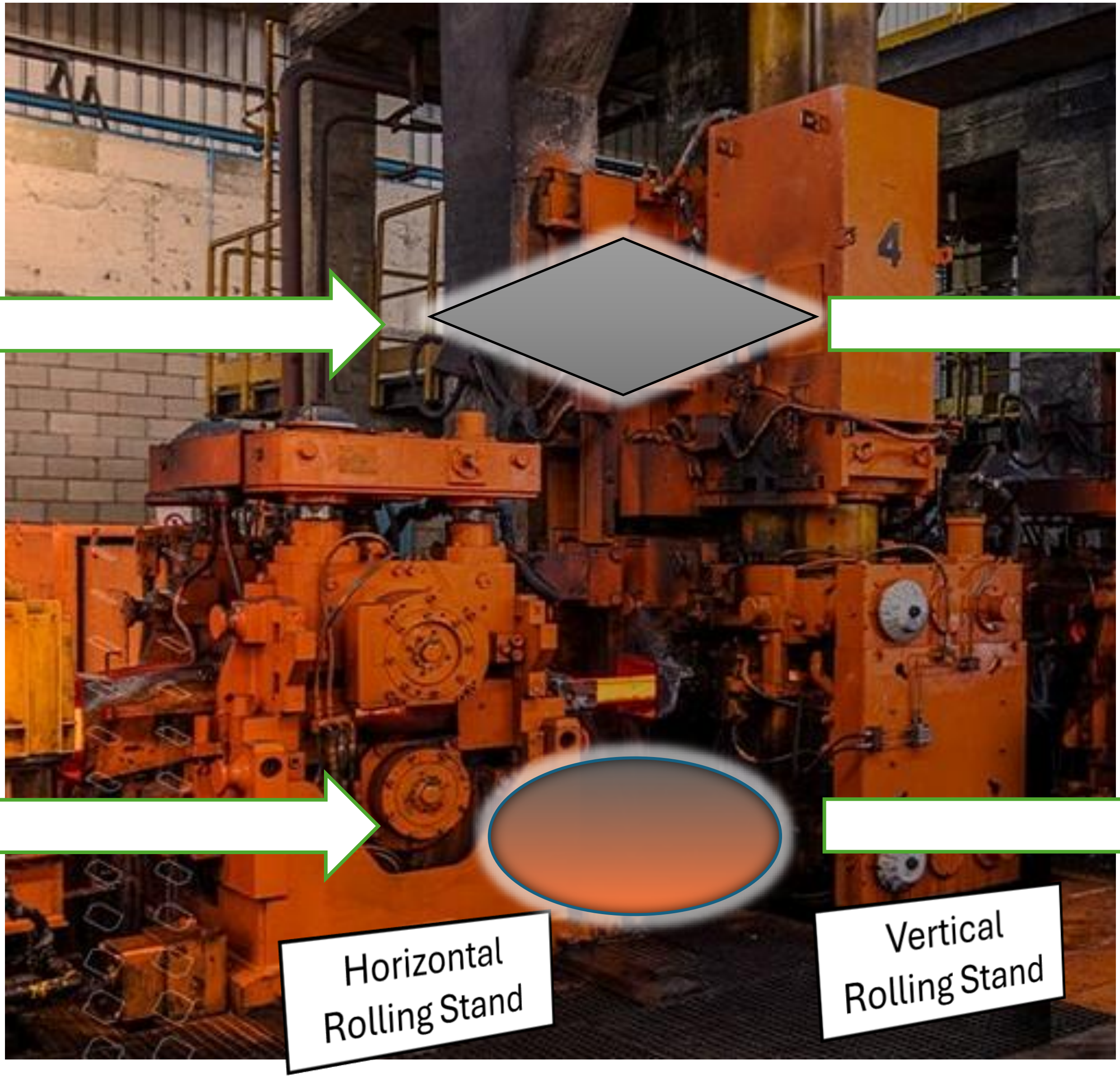
Maximizing **area reduction ratio**



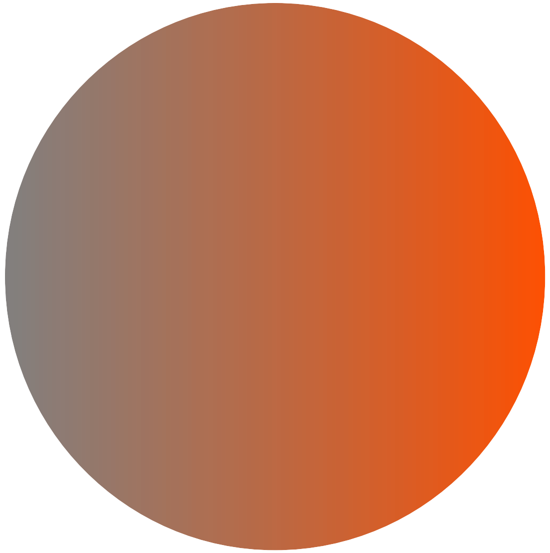
Rolling pass sequence

Square-Diamond-Square

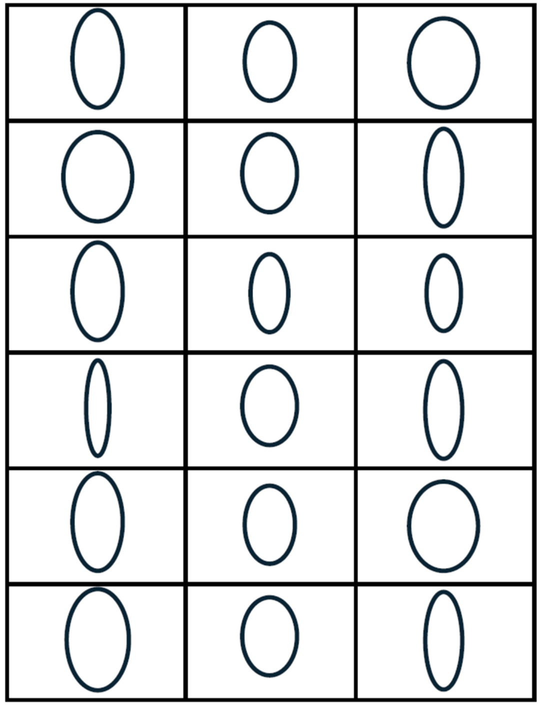
Round-Oval-Round

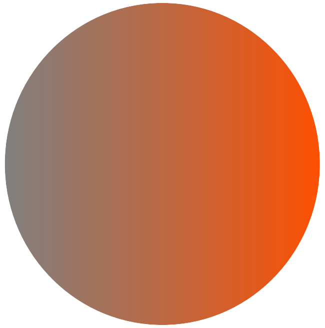


Round-Oval-Round Pass



Probable Ovals



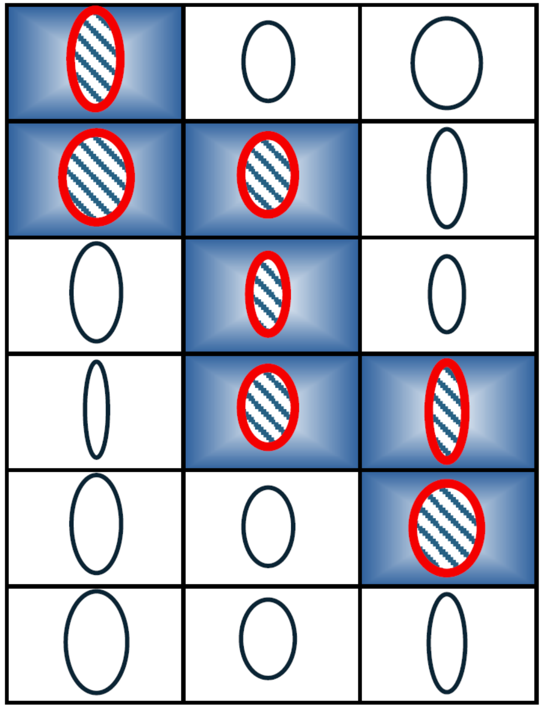


Required perfect shape

Input Round → **Intermediate Oval** → **Output Round**

Round-Oval-Round Pass

Feasible Ovals

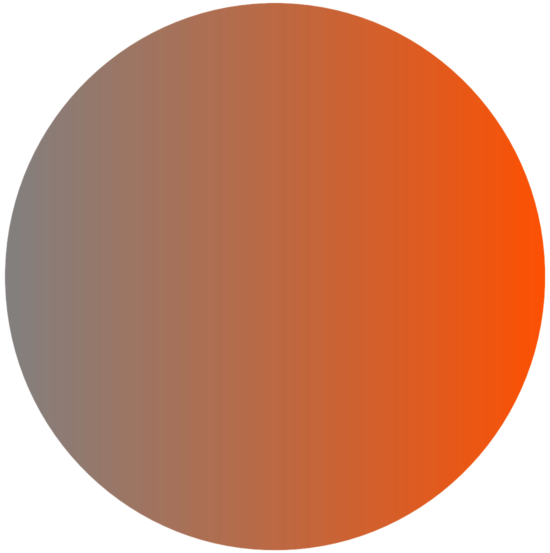


Input Round

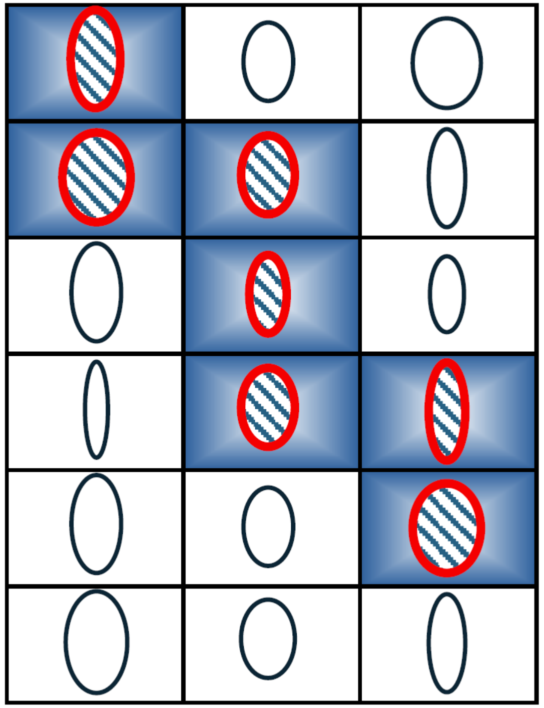
Intermediate Oval

Output Round

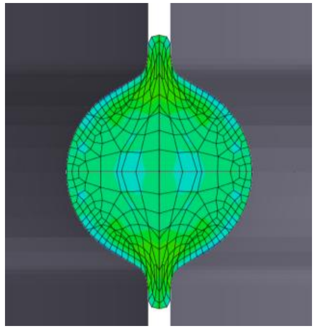
Round-Oval-Round Pass



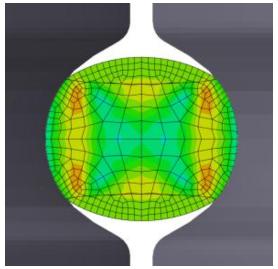
Un-feasible Ovals



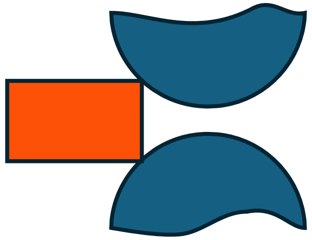
Over Fill



Under Fill



Large Bite Angle



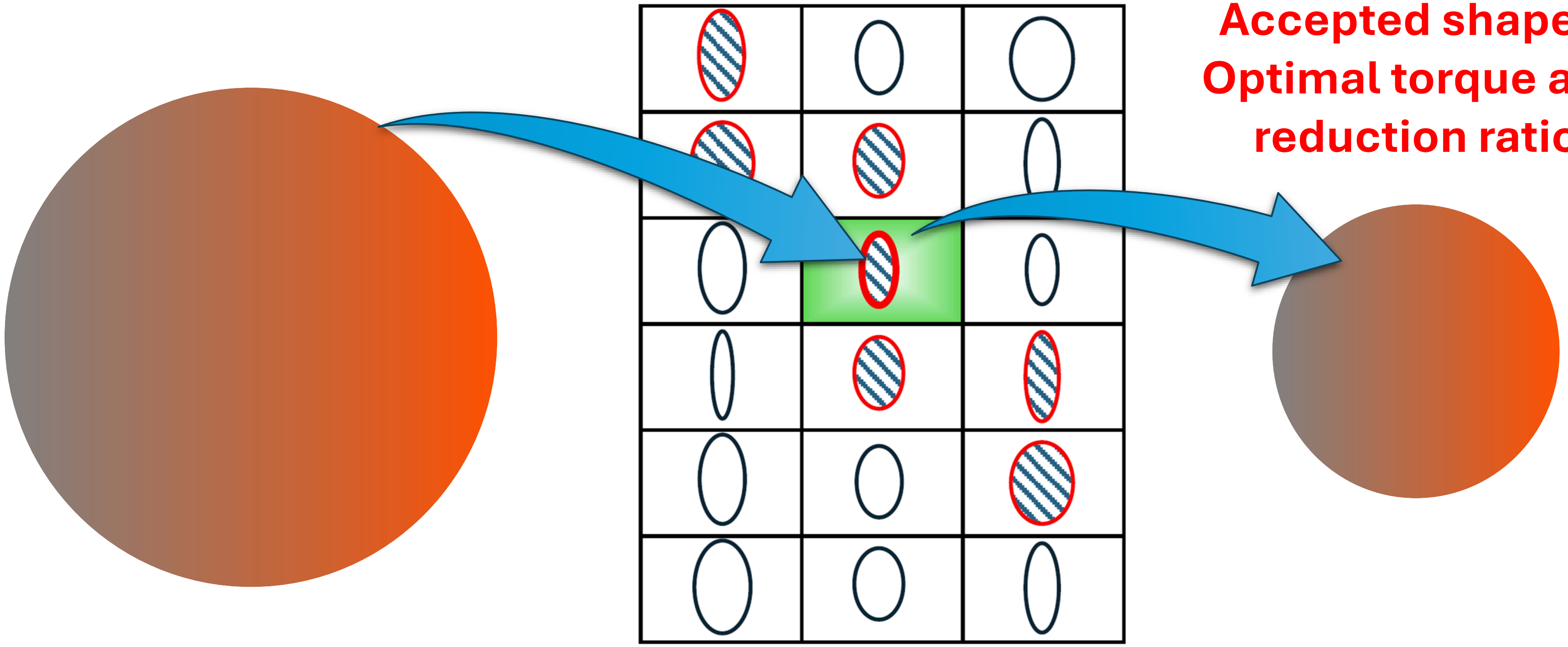
Input Round

Intermediate Oval

Output Round

Round-Oval-Round Pass

Optimal Oval



Accepted shape + Optimal torque and reduction ratio

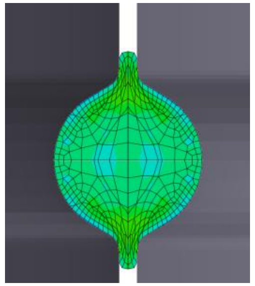
Input Round → **Intermediate Oval** → **Output Round**

Optimization Problem Formulation

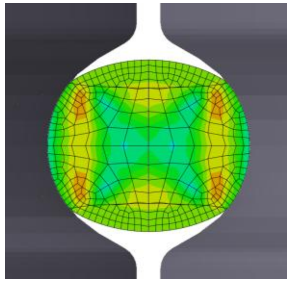
Objectives

- Minimizing the rolling torque
- Maximizing the area reduction ratio

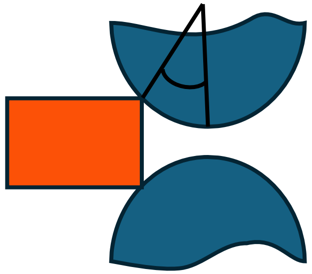
Constraints



Over fill



Underfill



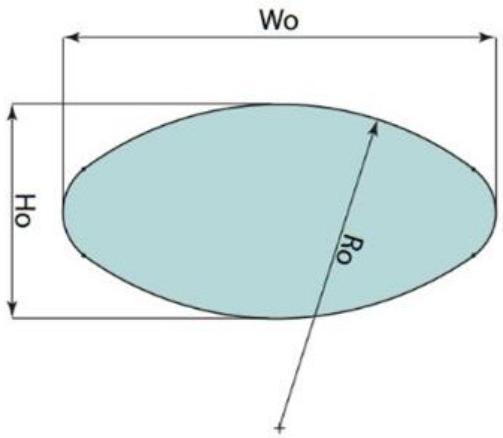
Bite angle

Design Parameters

Oval geometry

Radius

Depth



Challenges

Accurate Rolling Process Modelling

1

How to calculate the rolling parameters according to the design variables

Finding the Optimal Solution
Optimal Oval Shape

2

How do we find the optimal solutions when so many solutions

Challenges

Optimal Oval

Accurate Rolling Process Modelling

- Mathematical models are not available
    - Complicated process
    - Many process parameters
- Old empirical methods yield high margin of error
- Trial and error is so expensive
- Finite element modeling

Challenges

Optimal Oval

Accurate Rolling Process Modelling

- Finite element modeling

Two Step solution:

1. Finite element
2. Verification

1

2

Challenges

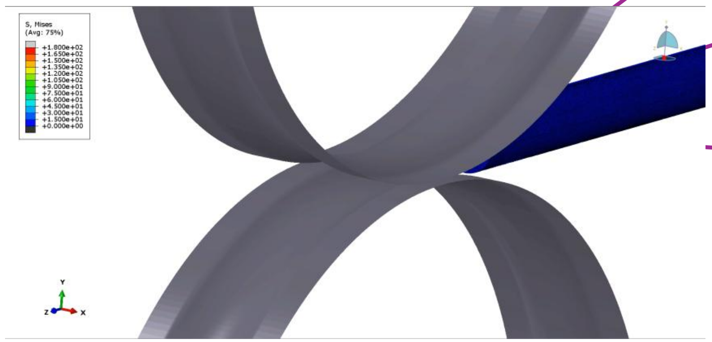
Accurate Rolling Process Modelling

1

Step 1

Finite Element

- **Abaqus Finite Element**
- Rolling FEM
  - Round-Oval
  - Oval-Round



Transient dynamic

Non-linear

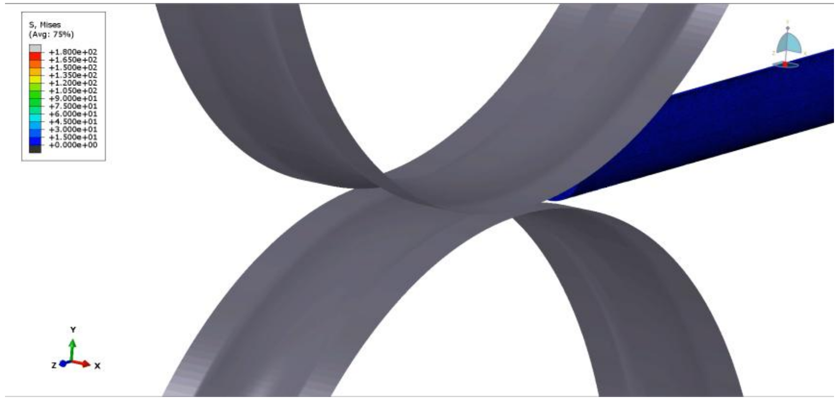
Explicit

Challenges

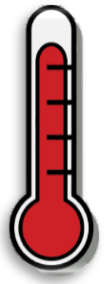
Step 1

Finite Element

- Abaqus Finite Element
- **Rolling FEM**
  - Round-Oval
  - Oval-Round

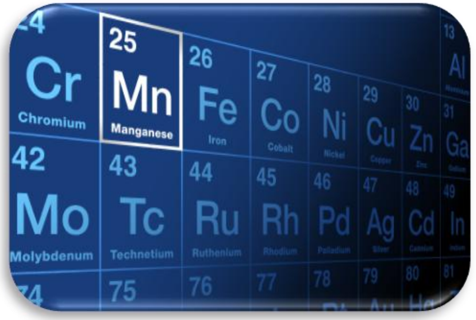


Accurate Rolling Process Modelling

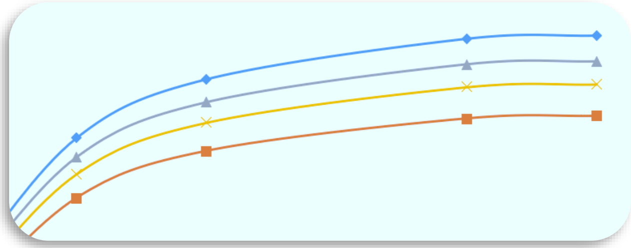


Temperature

Chemical Composition



Stress Strain curve & Strain Rate Effect



Challenges

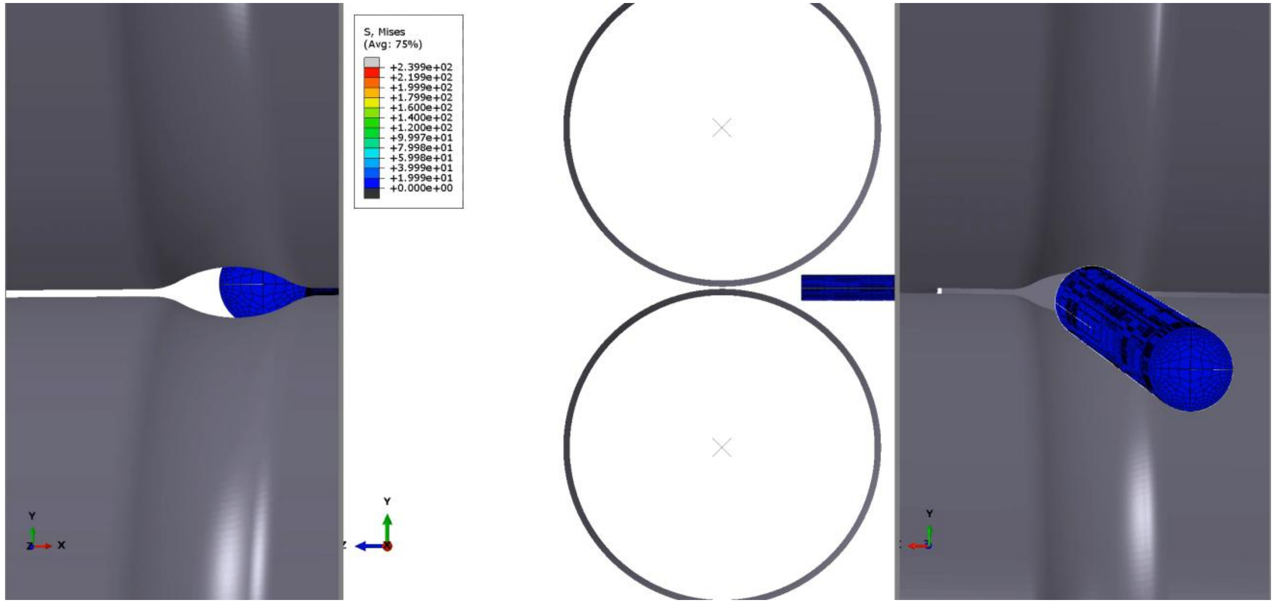
Accurate Rolling Process Modelling

1

Step 1

Finite Element

- Abaqus Finite Element
- Rolling FEM
- **Round-Oval**
    - Oval-Round



Challenges

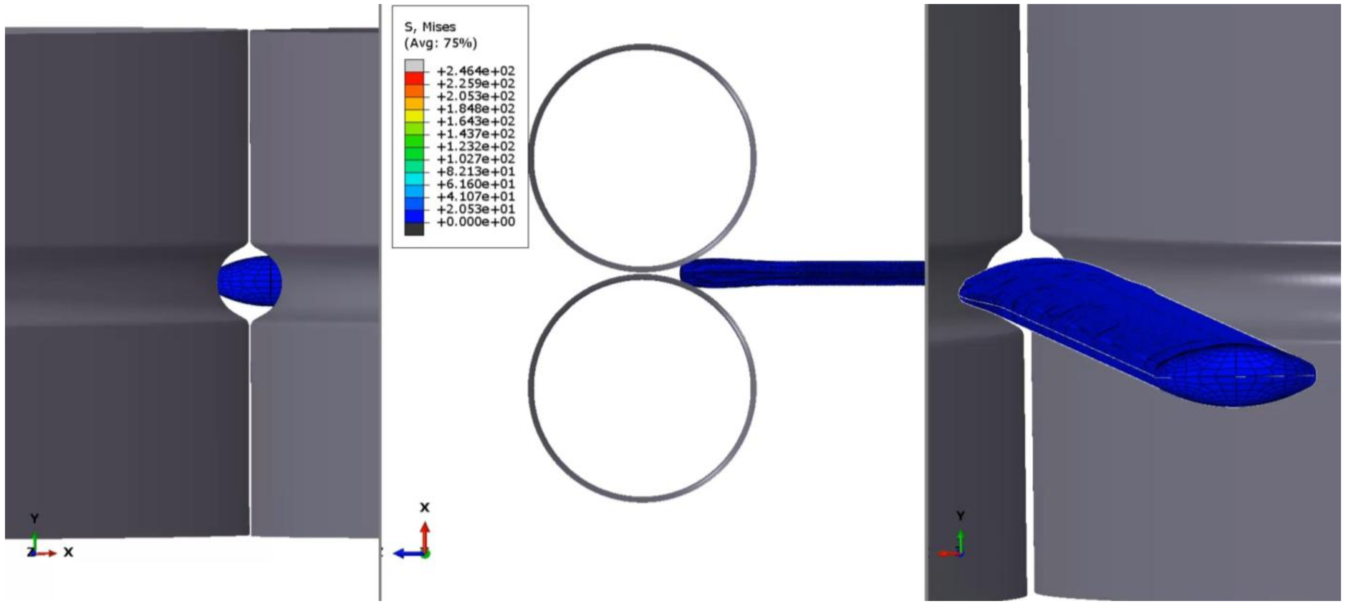
Accurate Rolling Process Modelling

1

Step 1

Finite Element

- Abaqus Finite Element
- Rolling FEM
  - Round-Oval
- **Oval-Round**



Challenges

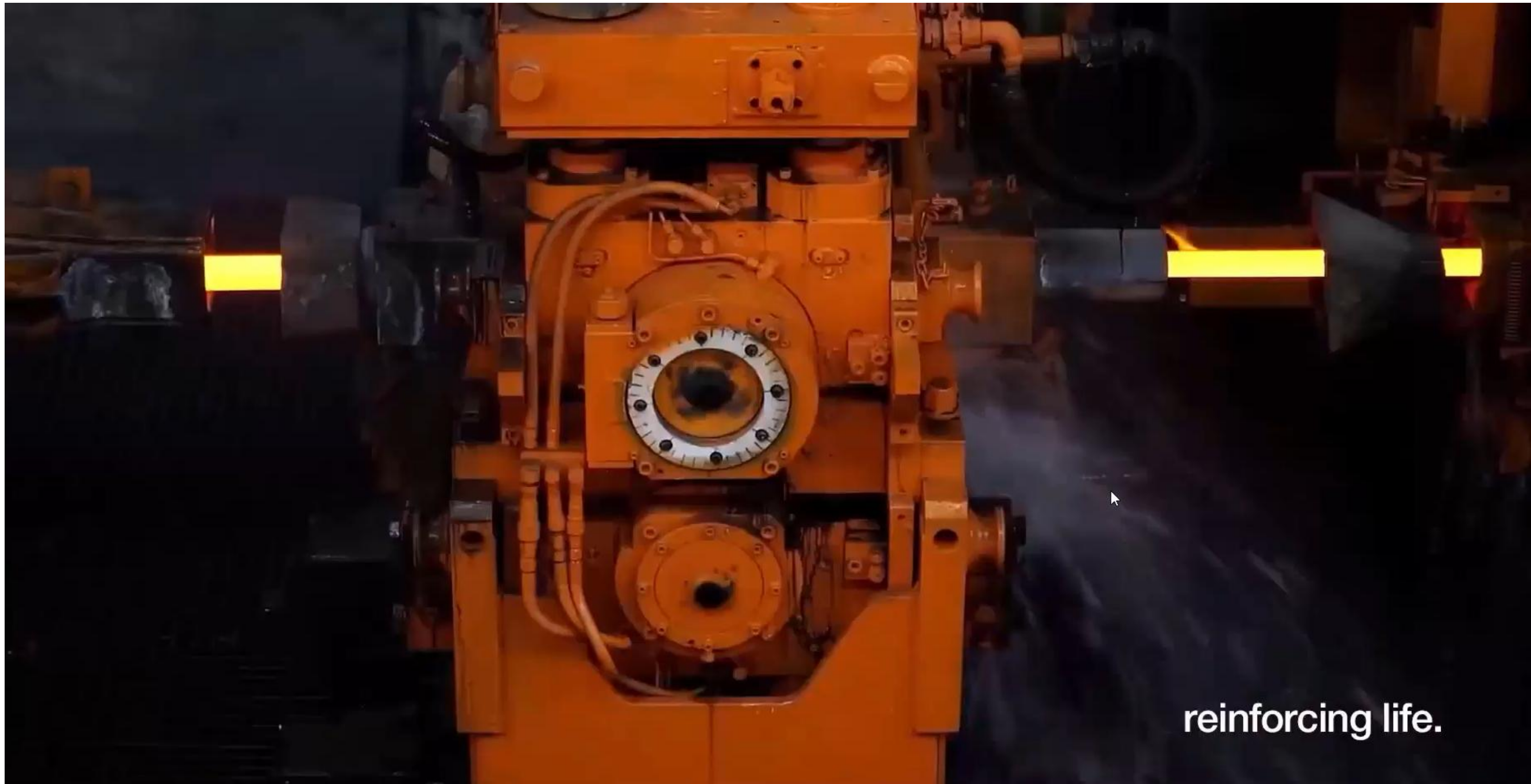
Verification of FE

Accurate Rolling Process Modelling

1

Step 2

- Experimental verification on the MKS rolling mill
  - Six experimental trials



MKS elmarakbysteel

Challenges

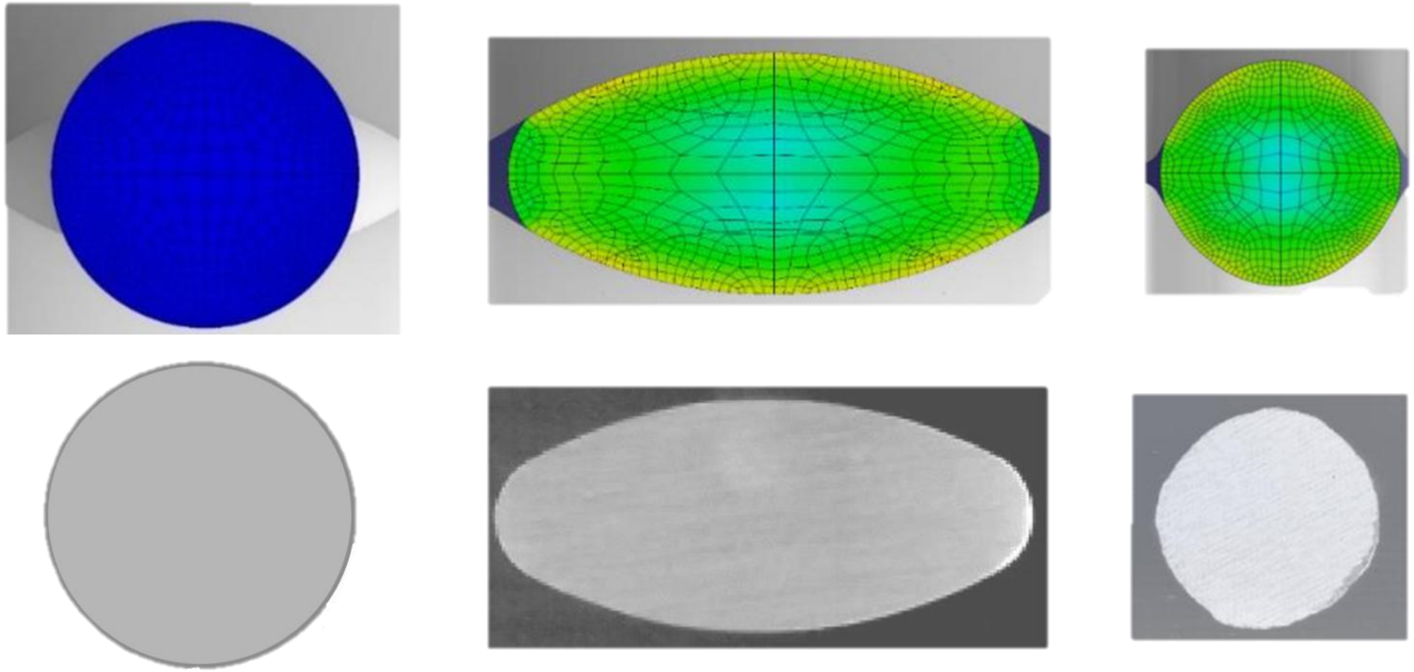
Verification of FE

Accurate Rolling Process Modelling

1

Step 2

- Actual experiment
  - Six Experimental trial
- **Results comparison**



Challenges

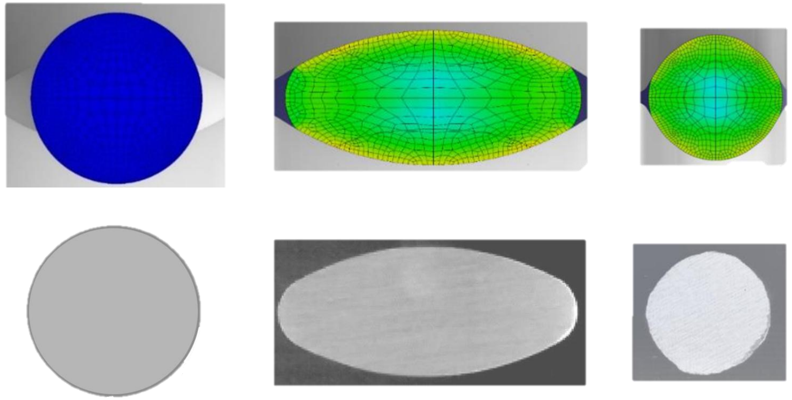
Accurate Rolling Process Modelling

1

Verification of FE

Step 2

- Actual experiment
  - Six Experimental trial
- **Results comparison**



Less than 0.5% error in Torque

Less than 1.5% error in Reduction ratio

Less than 0.1% error in Area

Challenges

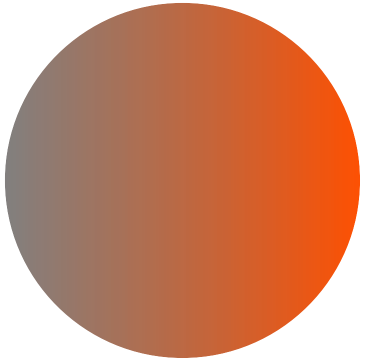
Optimal Solution
Optimal Oval Shape

2

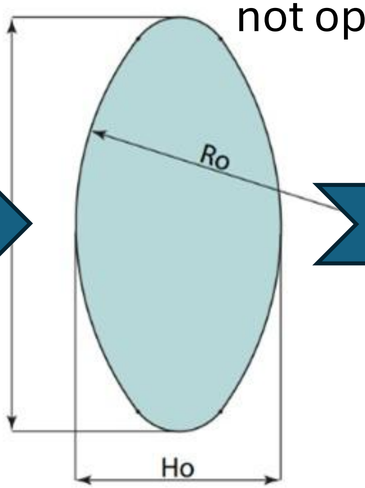
Challenges

Optimal Oval

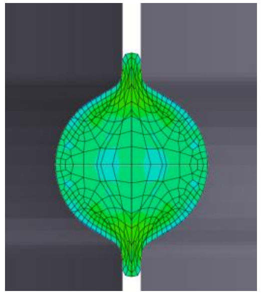
1st pass
Optimal solution



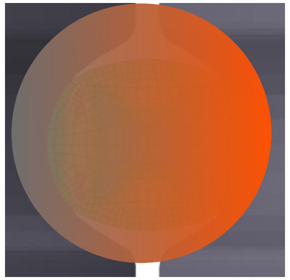
Optimal solution
Min. Torque or Max. Reduction



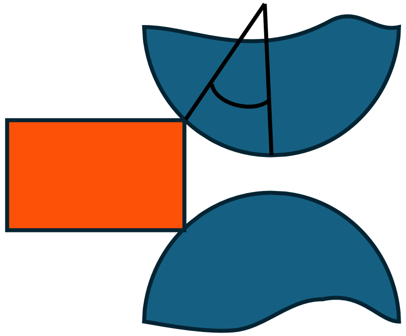
2nd pass
Maybe
not optimal or not compatible



Overfill



Underfill

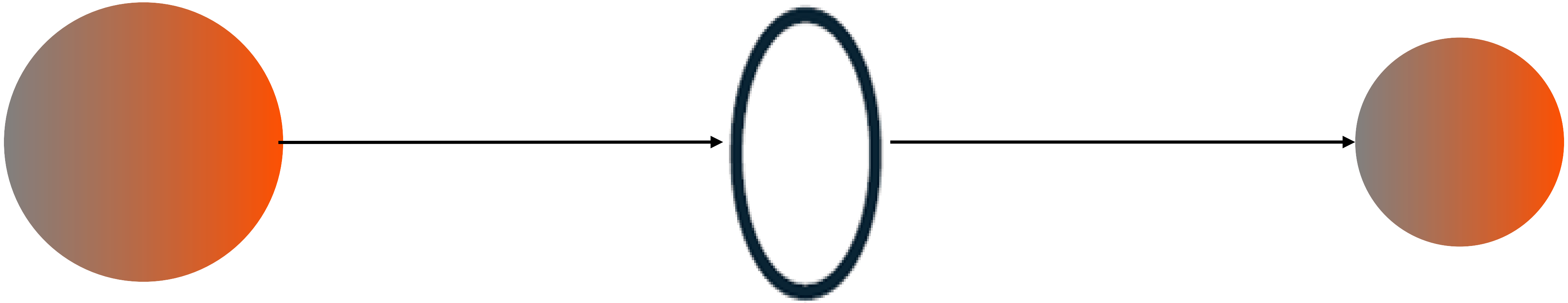


Bite angle

Challenges

Optimal Oval

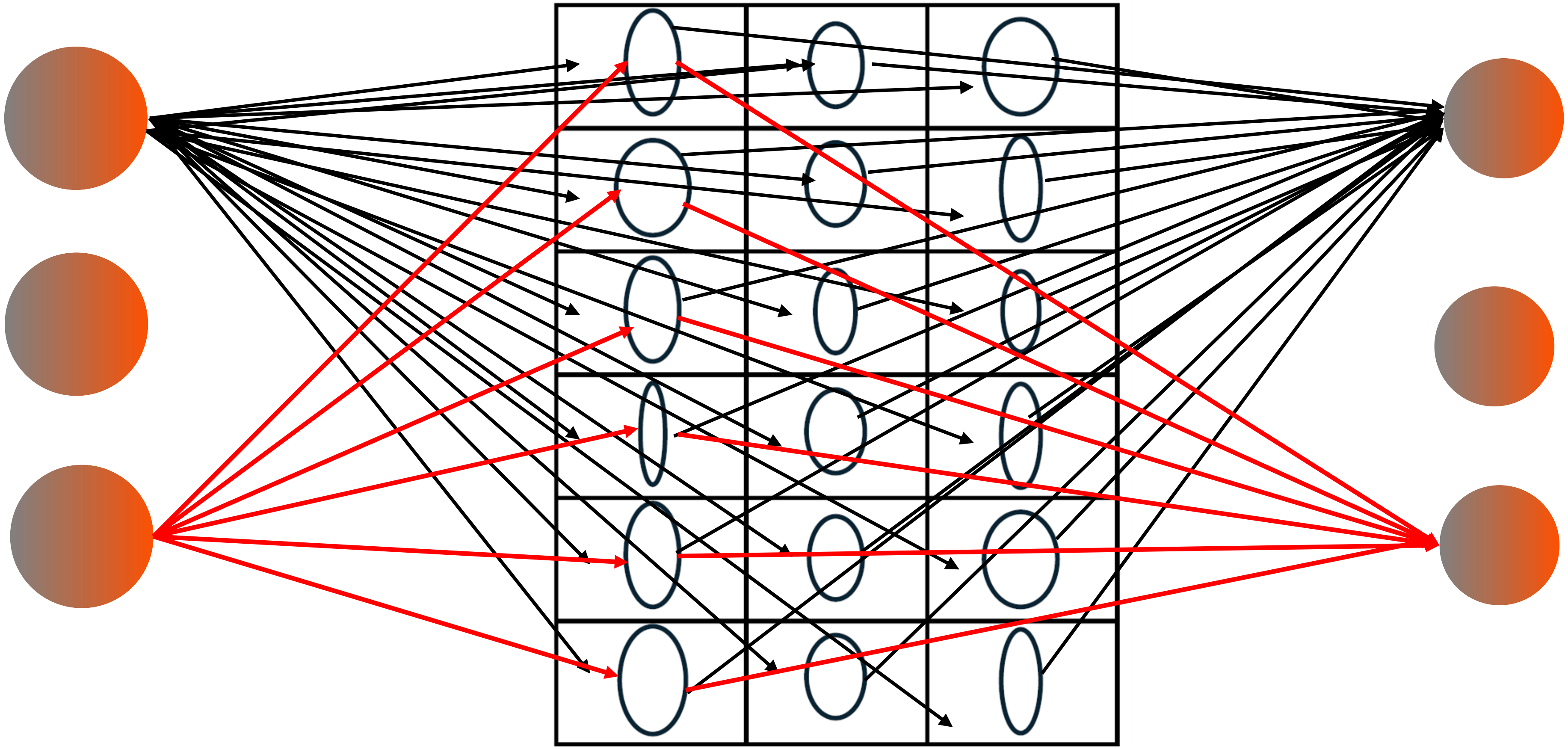
If the two passes are solved simultaneously, we can get the total optimal solution



Challenges

Optimal Oval

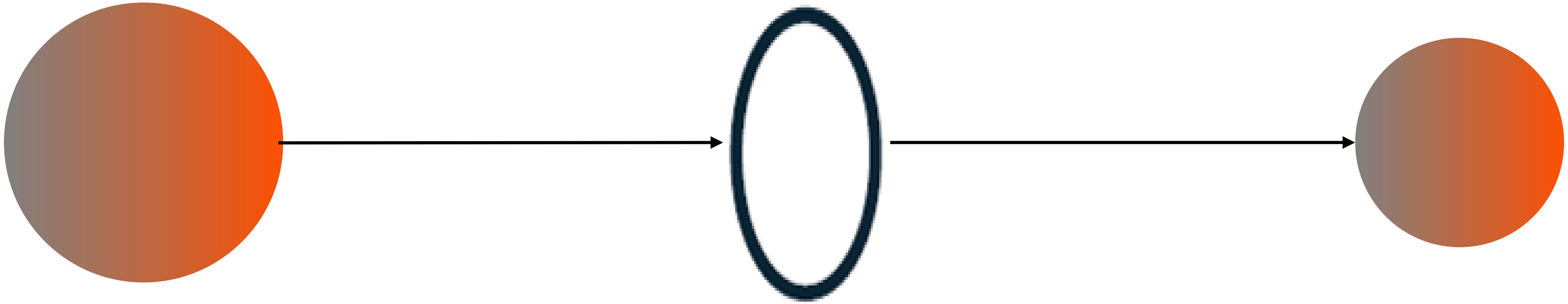
- Required so many trials



Challenges

Optimal Oval

We Used data analysis and regression tools to get **META-MODEL** to solve the rolling process instead of FEM



- Two-step solution:
    1. Double stages FEM
    2. Polynomial Meta-model and verification

Challenges

Optimal Oval

2

Step 1

Double stages FEM

- Round-Oval and Oval-Round passes FEM
- Annealing process between the two passes to relief the residual stresses

More complicated
but
more accurate

Challenges

Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- Automation of Rolling FEM
- Data analysis and regression
- Rolling meta-model equations
- Optimization result

Challenges

Optimal Oval

2

Step 2

Polynomial Meta-model

- **Design of Experiment**
- Automation of Rolling FEM
- Data analysis and regression
- Rolling meta-model equations
- Optimization result

- Full Factorial
- Three factors , 4,4,6 Levels
- 96 Total runs

Input Round Diameter	Oval Depth	Oval Radius
22	4.5	25
22.5	5	26.5
23	5.25	28
23.5	5.5	30
-	-	33
-	-	36

Challenges

Optimal Oval

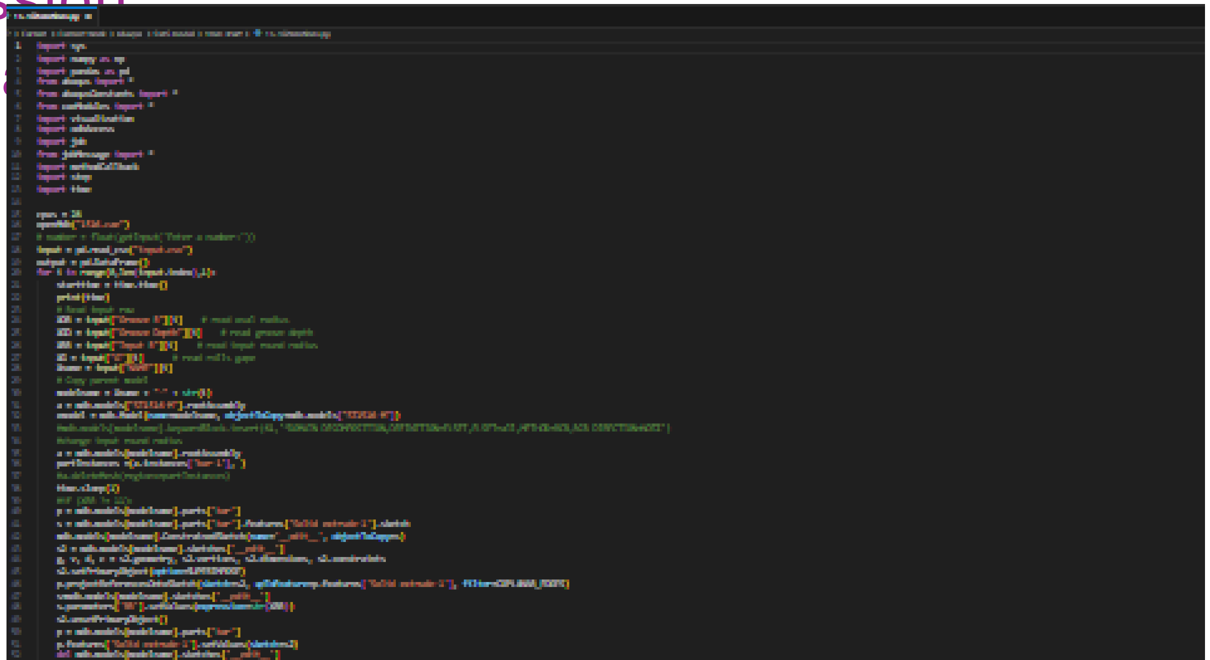
2

Step 2

Polynomial Meta-model

- Design of Experiment
- **Automation of Rolling FEM**
- Data analysis and regression
- Rolling meta-model equa
- Optimization result

- Python Code
- Extract Output



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Challenges

Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- **Automation of Rolling FEM**
  - ➢ Python Code
  - ➢ Extract Output
- Data analysis and regression
- Rolling meta-model equation
- Optimization result

Wo	Ho	Wo/Ho	Reduction ST15	To	Dr	Rr	ST16 Gap	Ar	Wr	Hr	W/H B	Reduction ST16	Tr	Total Reduction	Total Torque
28.28	12.42	2.28	29.00%	6.24	7.5	8.5	2	222.16	16.30	17.02	0.95	17.62%	3.42	41.51%	9.66
27.70	12.92	2.14	26.23%	5.39	7.5	8.5	2	229.11	17.09	17.02	0.99	18.23%	3.67	39.68%	9.06
28.79	11.93	2.41	30.88%	6.69	7.5	8.5	2	215.17	15.69	17.01	0.91	18.03%	3.36	43.35%	10.04
28.18	12.42	2.27	28.04%	5.86	7.5	8.5	2	223.69	16.43	17.02	0.95	18.16%	3.54	41.11%	9.40
27.61	12.92	2.14	25.35%	5.27	7.5	8.5	2	229.91	17.20	17.02	1.00	18.91%	3.85	39.47%	9.12
28.68	11.93	2.41	29.94%	6.40	7.5	8.5	2	216.80	15.80	17.02	0.92	18.52%	3.49	42.92%	9.89
28.10	12.42	2.26	27.19%	5.61	7.5	8.5	2	224.94	16.56	17.02	0.96	18.66%	3.69	40.78%	9.30
27.57	12.92	2.13	24.58%	5.17	7.5	8.5	2	230.61	17.33	17.02	1.01	19.49%	3.92	39.28%	9.09
29.93	10.93	2.74	34.70%	7.81	7.5	8.5	2	199.77	14.45	17.02	0.84	19.46%	3.33	47.40%	11.14
28.59	11.93	2.40	28.91%	6.19	7.5	8.5	2	218.68	15.94	17.02	0.93	19.01%	3.63	42.42%	9.82
28.02	12.42	2.26	26.26%	5.65	7.5	8.5	2	226.16	16.69	17.02	0.97	19.25%	3.82	40.45%	9.47
27.51	12.92	2.13	23.69%	5.01	7.5	8.5	2	231.32	17.45	17.02	1.01	20.19%	4.13	39.10%	9.15
29.76	10.93	2.72	33.18%	7.53	7.5	8.5	2	202.74	14.66	17.02	0.85	20.11%	3.42	46.62%	10.94
28.48	11.92	2.39	27.68%	6.12	7.5	8.5	2	220.71	16.11	17.02	0.94	19.65%	3.78	41.89%	9.90
27.95	12.42	2.25	25.07%	5.41	7.5	8.5	2	227.49	16.86	17.02	0.98	20.07%	4.03	40.11%	9.44
27.46	12.92	2.12	22.66%	4.77	7.5	8.5	2	232.05	17.60	17.02	1.02	21.00%	4.24	38.90%	9.01
29.62	10.93	2.71	32.00%	7.28	7.5	8.5	2	205.16	14.82	17.02	0.86	20.56%	3.57	45.98%	10.85
28.42	11.92	2.38	26.65%	5.92	7.5	8.5	2	222.27	16.25	17.02	0.94	20.22%	3.97	41.48%	9.89
27.89	12.42	2.25	24.19%	5.23	7.5	8.5	2	228.42	16.99	17.02	0.99	20.67%	4.15	39.86%	9.38
29.22	12.43	2.35	31.12%	6.47	7.5	8.5	2	224.15	16.45	17.02	0.96	18.08%	3.59	43.58%	10.06
28.60	12.92	2.21	28.28%	5.79	7.5	8.5	2	230.67	17.29	17.02	1.00	19.04%	3.85	41.94%	9.64
29.74	11.93	2.49	32.95%	7.05	7.5	8.5	2	217.23	15.80	17.02	0.92	18.45%	3.49	45.32%	10.54
29.10	12.42	2.34	30.06%	6.35	7.5	8.5	2	225.79	16.63	17.02	0.97	18.73%	3.69	43.16%	10.04
28.52	12.92	2.21	27.30%	5.73	7.5	8.5	2	231.49	17.44	17.02	1.01	19.85%	3.97	41.73%	9.70
29.63	11.93	2.48	31.99%	6.87	7.5	8.5	2	219.01	15.95	17.02	0.93	18.94%	3.61	44.87%	10.48
28.99	12.43	2.33	29.16%	6.12	7.5	8.5	2	227.01	16.75	17.02	0.97	19.34%	3.87	42.86%	9.99
28.45	12.92	2.20	26.44%	5.55	7.5	8.5	2	232.12	17.58	17.02	1.02	20.57%	4.07	41.57%	9.62
30.94	10.93	2.83	36.70%	8.24	7.5	8.5	2	201.60	14.49	17.02	0.84	19.83%	3.43	49.25%	11.67
29.49	11.93	2.47	30.84%	6.69	7.5	8.5	2	220.89	16.11	17.02	0.94	19.60%	3.76	44.40%	10.45

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Challenges

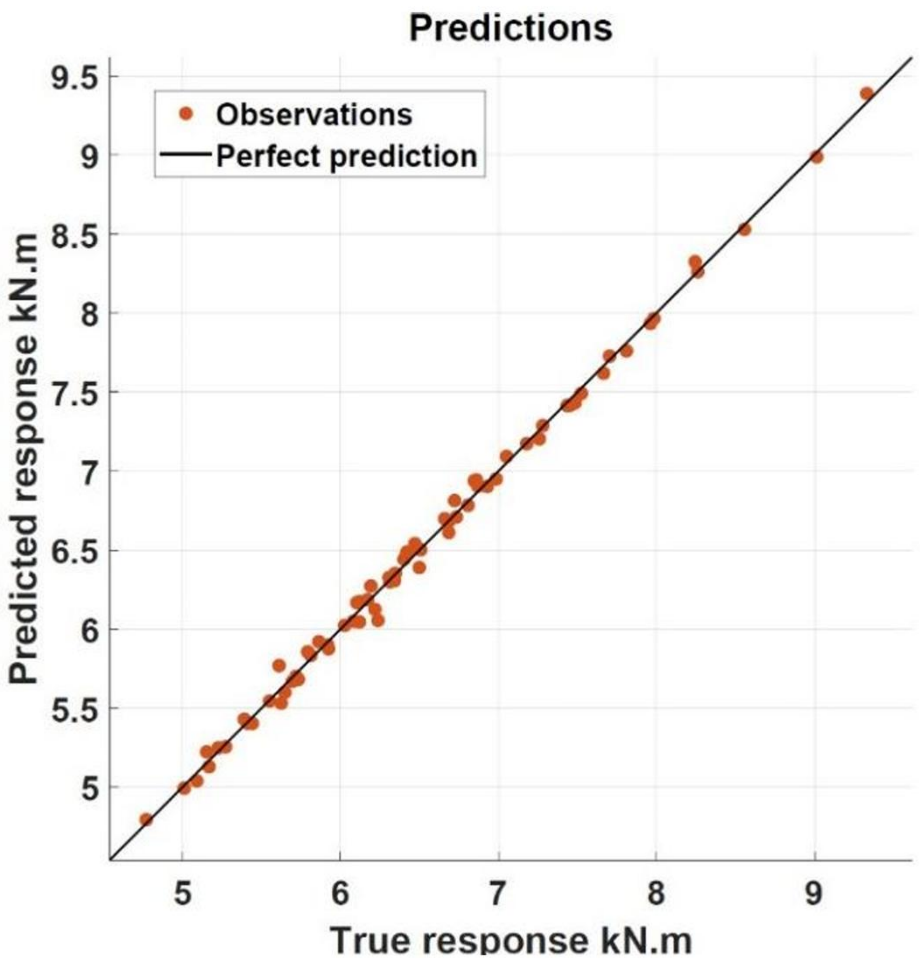
Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- Automation of Rolling FEM
- **Data analysis and regression**
- Rolling meta-model equations
- Optimization result



Challenges

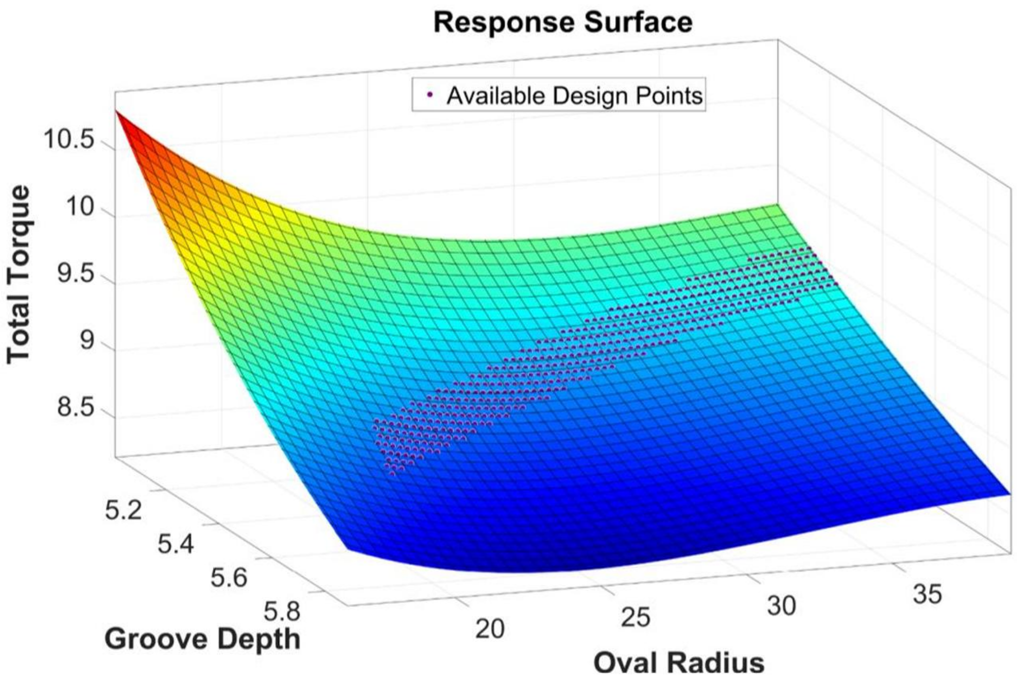
Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- Automation of Rolling FEM
- **Data analysis and regression**
- Rolling meta-model equations
- Optimization result



Challenges

Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- Automation of Rolling FEM
- Data analysis and regression
- **Rolling meta-model equations**
- Optimization result

6 equations for Two passes

Challenges

Optimal Oval

2

Step 2

Polynomial Meta-model

- Design of Experiment
- Automation of Rolling FEM
- Data analysis and regression
- Rolling meta-model equations
- **Optimization result**

Searching in meta-model equations reached optimal oval dimensions

Maximum Reduction	↑ 13%

Optimal Torque Improvement	↓ 6%

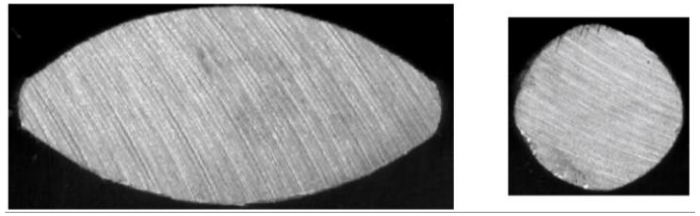
Challenges

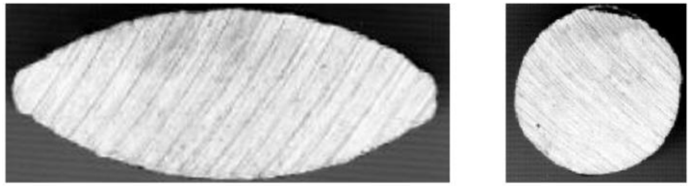
Optimal Oval

Step 2

Verification of the Optimization result

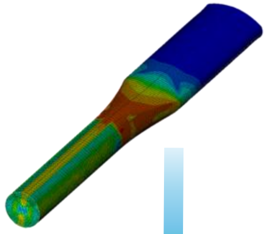
Meta-model result	Maximum Reduction	↑ 13%	Optimal Torque Improvement	↓ 6%
Experimental result	Maximum Reduction	↑ 13%	Optimal Torque Improvement	↓ 7%





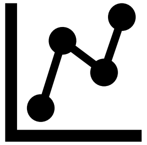
Overall General Optimization Method

1 Verified Double Stage FEM Using Abaqus software



2 Automated FEM using python code

3 Data analysis and Meta-Model generation



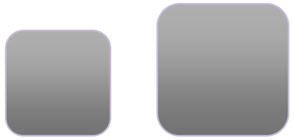
4 Finding optimal solutions Using the META-model equations

Applications for this Study

Improve the roll pass design for the existing rolling mill plants

- **Minimize the rolling torque and energy consumption**
- **Or Maximize area reduction ratio**
  - ❑ **To produce smaller products from the same production line**

  - ❑ **To produce the same products from larger billet size**



Application at Elmarakby Steel rolling mill #1

- **Production improvement by** 20%

- **Rolling from 150x150 billet instead of 130x130**

  Without adding any rolling stands
  Without upgrading the existing equipment
  Without reducing the production capacity

Thank you