DEVELOPMENT OF 600MM U-PILE ON HEAVY SECTION MILL USING FINITE ELEMENT ANALYSIS AND SMALL SCALE LEAD TRIALS*

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Abstract
This paper aims to present the development of a 600mm U-Pile that was done in Gerdau's Ouro Branco Heavy Section Mill in order to feed the local market with a product.The focus of this study is to show the developmental process the Mill went through until it was prepared for hot trials. All roll pass and guide designs were developed by our own team. Analytical tools like Finite Element Analysis and reduced scale lead trials will be shown and how these tools impacted on the development timeframe and accuracy of the final results on steel.
The final results on the steel product, the rolling parameters such as separating forces, trust forces, torque, product behavior, spreading, elongation, and others will be compared to results predicted by the tools and how to interpret them.
Keywords: U-Pile; roll pass designs; Finite Elements Analysis

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1 INTRODUCTION

The Heavy Section Mill of Gerdau Ouro Branco began its operation in 2002 and it had the objective of supplying the local construction market, with W and HP beams, becoming an option in front of the folded beans and the concrete.

Over the years, Gerdau Ouro Branco's Heavy Section Mill (HSM-OB) has added new products in its portfolio, such as new W and HP beams, angles, channels, sleepers and sheet pilings.

One of the last products developed in HSM-OB was the sheet piling 600mm U-Pile to feed the local market with a product.

According to the "types of sheet piling" article [1] of Pile Buck Magazine, "*The term sheet piling refers to any retaining wall type that is a) installed into the ground by driving or pushing, rather than pouring or injection, and b) is of relatively thin cross section and low weight so that the weight of the wall does not assist in the wall's stability".*

Our market intelligence team pointed out the kind of sheet pile that would be important to develop through market analysis.

The marketing team suggested a sheet piling with 600mm width and 10 mm thickness, named EPG600.

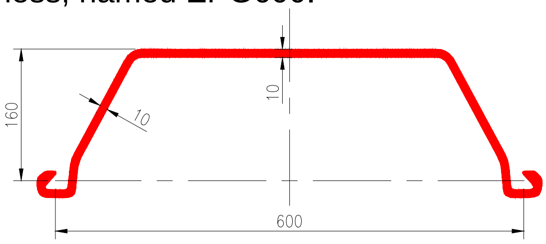
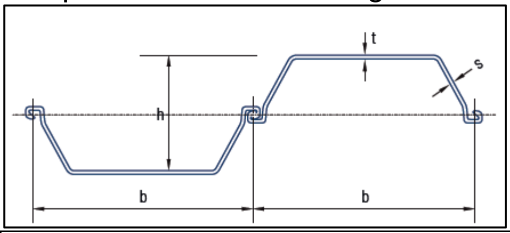


Figure 1. EPG600

After that, the HSM-OB roll pass design and process team evaluated the technical feasibility to produce this product.

According to Gerdau's EPG600 catalog [2], this product is suitable for a variety of applications, and its use may be temporary or permanent. Besides that, it has as main marketplace: the real estate market (underground contents), infrastructure (drainage of ditches and containment of ports, rivers and canals) and industrial.

Some EPG600 dimensional characteristics and shape are shown in the figure 2.



EPG 600		
b (mm)		600
h (mm)		320
t (mm)		10
s (mm)		10
Area (cm^2)		92,2
Perimeter (cm^2/cm)		185
Mass	Profile (kg/m)	72,1
	Wall (Kg/m^2)	120,2

Figure 2. EPG600 – main dimensions

Figure 3. EPG600

All the roll pass design project (passes, groves, guides) were developed by the Gerdau Section Mill Team.

After project elaboration, in order to predict the results and to look for small improvements, we use as an analytical tool a software of Finite Element Analysis (FEA), called FORGE by Transvalor. An example of the FEA simulation is show in the figure 4.

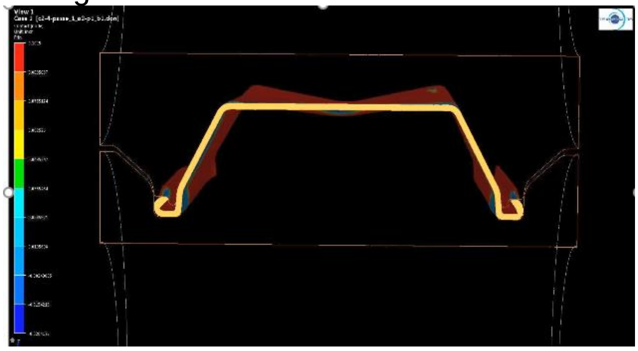


Figure 4. Last pass of the FEA simulation - EPG600

After that, we tested the roll design in a reduced scale lead trials, called LAB Mill in Midlothian Steel Mill – GLN – USA. In the figure 5 we have the samples of all passes of LAB Mill.

Figure 5. Samples LAB Mill samples- EPG600

So, we performed a steel hot test in HSM-OB with great success.

Figure 6. Hot test bar in the cooling bed

The focus of this study is to show the developmental process which the Mill went through until it was prepared for hot trials and how these tools impacted on the development timeframe and accuracy of the final results on steel.
In addition, the dimensional, quality and process results and the behavior of the hot steel tests will be compared with those predicted by the analytical tools.

2 MATERIAL AND METHODS

We split this development in 3 steps, before the hot test:

- Roll pass design project (grooves, rolls, pass schedule and guides)
- Simulation in finite element analysis (FEA)
- Reduced scale lead trials at LAB Mill

2.1 – Roll pass design project

As important inputs for the roll pass design project development, we can mention the learning acquired with the development of the EPG400 project in the previous year, as-well as the analysis of an old roll pass design SMS for the Larssen 31 (a similar product, but smaller).
In addition, our roll pass design team contacted Midlothian Steel Mill team as well as some external consultants for further information. After designing all rolling grooves, pass by pass, from the final product to the feedstock, the number one challenge was to distribute these groves and passes in the rolls, in reason of

the large final width of the product and hence the grooves width.
At HSM-OB we have available 2 duo-reversible breakdown mills and 2 duo-reversible finishing mills, in Tandem.
We distributed the grooves in the rolls and then had its pass schedule made based on the groove design and the amount of draft work each mill would be able to do on each pass.
Some parameters must be observed in each pass in this step as: bite condition, spread, groove filling and rolling forces.
Greater absolute thickness absolute reductions must be performed in the initial passes because higher temperatures and lesser rolling forces as well as relative reductions in area.
In the final passes the absolute and relative reductions are low in order to ensure the dimensional and superficial quality of the product goals. Table 1 shows the pass schedule for EPG600.

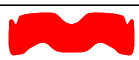
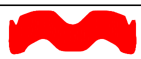
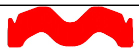
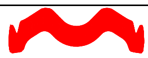
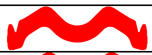
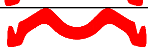
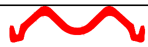
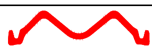
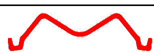
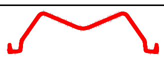
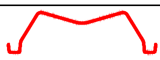
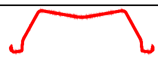
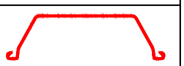
Mill	Pass	Groove name	Shape
---	---	---	
BD1	1	K	
BD1	2	J	
BD1	3	J	
BD1	4	J	
BD1	5	H	
BD1	6	H	
BD1	7	H	
BD2	1	G	
BD2	2	F	
BD2	3	E	
C2	1	D	
C2N	2	C	
C2N	3	B	
C2	4	A	

***Table 1**. EPG600 Pass Schedule*

After determining the rolls and passes configuration, the next step was the preparation of guides and strippers basic designed for all the stands. When the results of subsequent steps with FEA analysis and the LAB mill trials, final mill trial versions of grooves, passes and guides would be determined.

<u>2.2 – Simulation in finite element analysis (FEA)</u>

The next step was the simulation of the roll pass design project in Finite Element Analysis. For that, we used a software called FORGE by Transvalor.
To perform the simulation in the FEA Software, the inputs are [4]:

- material information which may be a cross-section design in DXF format or the result simulated in the previous pass
- Roll/groove design in DXF format
- Temperature in Fahrenheit
- Type of steel
- Type friction surface and of heat exchange
- Mesh size
- Roll gap

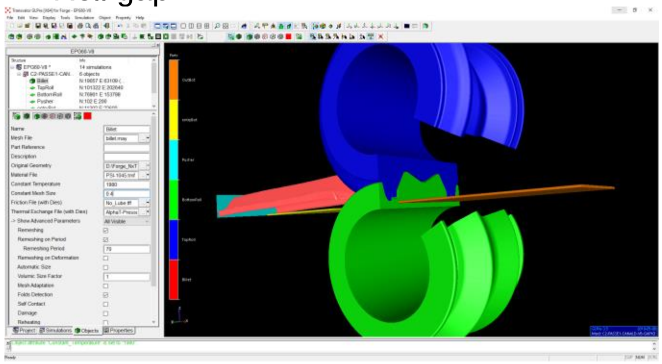


Figure 7. FEA inputs – pass groove D

The processing time of the simulation varies according to the pass complexity, material length, computer processing speed and mesh size
With this, we can simulate all the passes, one by one, assessing:

- the material behavior in the pass

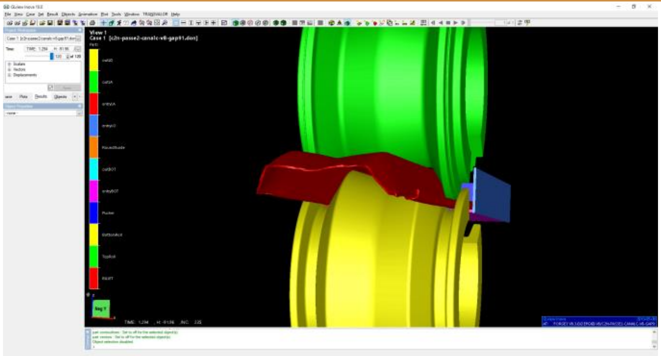


Figure 8. material behavior – pass groove C

- Groove filling and spread.

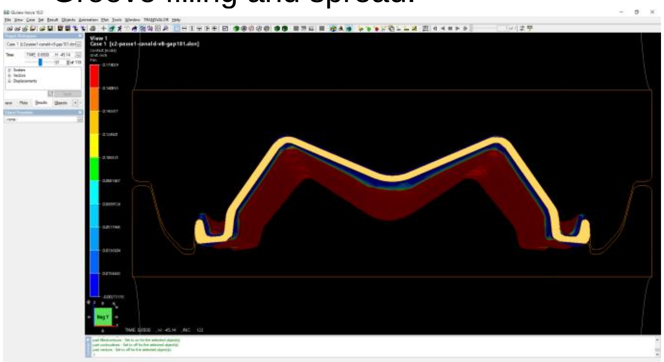


Figure 9. groove filling and spread – pass groove D

- Bite forces, rolling forces and torque.

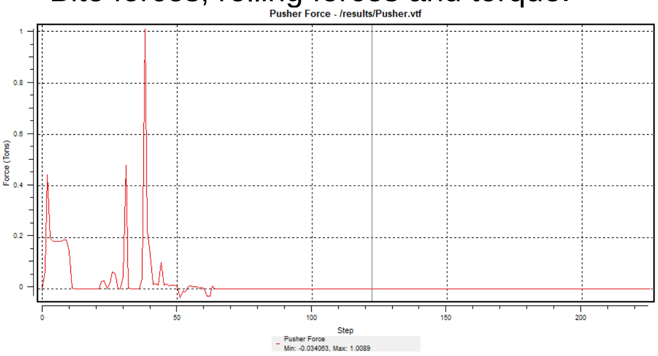


Figure 10. Bite force – pass groove D

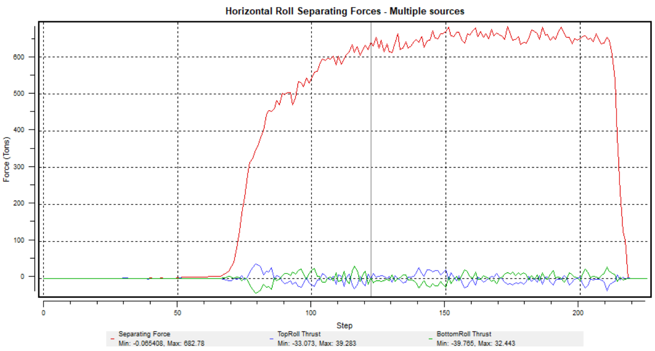


Figure 11. Rolling force – pass groove D

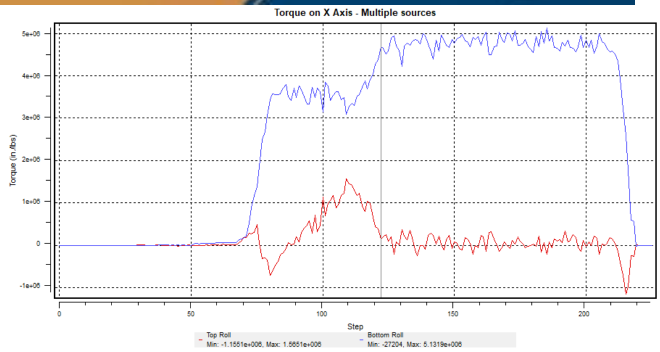


Figure 12. Torque – pass groove D

All passes were simulated in the FEA software, presenting good results.

2.3 – Reduced scale lead trials at LAB Mill

After the simulation in FEA software and roll pass design adjustments, the next step was the reduced-scale lead trial at LAB Mill in Midlothian Steel Mill - TX USA, to ratify the effectiveness of the roll design before the hot mill trial.

Figure 13. Lab Mill

Figure 14. Lab Mill

Figure 15. Lab Mill

The dynamic deformation behavior (spread, elongation) of lead at ambient temperature (25ºC) is like hot steel.

For a week, we did simulations of all passes, analyzing the results and seeking improvements in the design. We took sample of all passes.

Figure 16. Simulation samples

At the end of week, we obtained the perfect lock in samples, at the ends of the bar (nose and tail).

Figure 17. Lock formation in a sample in Lab Mill

As the characteristic of the lock formation to EPG400, at the ends of the bar (nose and tail) obtained in Lab Mill trials were similar to the behavior of the lock in the whole bar in the hot test, we decided to move on to the next step and go to the hot mill trials.

2.4 – Hot trials

In the first hot trial we obtained a partial success because despite the project being stable in all passes and reaching the required dimensional values, we could not achieve a good lock formation throughout the bar.

Figure 18. Lock formation in the first hot test

We observed that in some intermediate passes there was not good filling at the lock except for the ends of the bar. Figure 19 shows the fill in groove C.

Figure 19. Groove C

We revised the roll design from the first passes to improve the filling in the intermediate grooves and with this ensure the lock throughout the bar.
We consolidated the modifications using FEA simulation again.
In the following trial we obtained total success in all the questions, including in the lock formation.

Figure 20. Lock formation in the last hot test

3 RESULTS AND DISCUSSION

The results obtained in the simulations by FEA and in the trials in lead and reduced scale in LAB Mill, were very close to expected in the project and that what was obtained in real.
Tables 2 and 3 show the comparison of predicted dimensions in the design with those obtained by the analytical tools and the hot trial.

Mill	Pass	G	Web thickness		
			FEA Simul.	Lab Mill	Hot test
---	---	---	0,0%	1,0%	---
BD1	1	K	0,4%	0,0%	---
BD1	2	J	-1,9%	0,2%	---
BD1	3	J	-3,3%	-1,9%	---
BD1	4	J	0,8%	-5,1%	5,7%
BD1	5	H	0,3%	3,6%	---
BD1	6	H	0,9%	4,2%	---
BD1	7	H	1,4%	7,2%	7,1%
BD2	1	G	1,9%	-6,2%	---
BD2	2	F	1,2%	-11,8%	---
BD2	3	E	4,1%	0,5%	11,8%
C2	1	D	2,1%	3,9%	---
C2N	2	C	4,3%	0,4%	-4,3%
C2	3	B	3,8%	-0,9%	---
C2N	4	A	4,0%	1,6%	7,0%

***Table 2**. Web thickness – Design x simulations*

Mill	Pass	G	Width		
			FEA Simul.	Lab Mill	hot test
---	---	---	0,0%	0,6%	---
BD1	1	K	-0,4%	-2,2%	---
BD1	2	J	0,1%	-0,1%	---
BD1	3	J	-0,4%	-0,7%	---
BD1	4	J	-0,9%	-1,7%	-1,4%
BD1	5	H	0,2%	-0,3%	---
BD1	6	H	-0,1%	-1,8%	---
BD1	7	H	-0,5%	-2,6%	-1,1%
BD2	1	G	-0,2%	-1,1%	---
BD2	2	F	-0,6%	-2,2%	---
BD2	3	E	-1,0%	-1,2%	-0,7%
C2	1	D	-0,2%	-1,4%	---
C2N	2	C	-0,5%	-2,3%	-1,0%
C2	3	B	-0,9%	-1,2%	---
C2N	4	A	-0,3%	-0,4%	-0,2%

***Table 3**. Width – Design x simulations*

The comparison between the theoretical roll force and Torque on the pass schedule (by Ekelund) and the calculation performed in the FEA software did not show good results, with differences of up to 200%. There is no force measurement in the Lab Mill and there are no load cells in the mills in HSM-OB.

Tables 4 show the comparison of predicted Rolling force (by Ekelund) in the pass schedule with that obtained by the analytical tools.

Mill	Pass	G	Rolling Force
			FEA Simul.
BD1	1	K	130,6%
BD1	2	J	42,5%
BD1	3	J	34,6%
BD1	4	J	45,8%
BD1	5	H	51,8%
BD1	6	H	29,8%
BD1	7	H	47,2%
BD2	1	G	72,8%
BD2	2	F	48,6%
BD2	3	E	94,6%
C2	1	D	269,6%
C2N	2	C	423,5%
C2	3	B	52,6%
C2N	4	A	234,5%

Table 4*. Roll Force – Design x simulations*

Tables 5 show the comparison of predicted Torque in the pass schedule with that obtained by the analytical tools.

Mill	Pass	G	Torque
			FEA Simul.
BD1	1	K	83,9%
BD1	2	J	57,8%
BD1	3	J	25,7%
BD1	4	J	13,5%
BD1	5	H	-7,4%
BD1	6	H	-18,0%
BD1	7	H	27,3%
BD2	1	G	139,7%
BD2	2	F	23,5%
BD2	3	E	74,2%
C2	1	D	-37,2%
C2N	2	C	-7,8%
C2	3	B	-29,9%
C2N	4	A	8,7%

Table 5*. Torque – Design x simulations*

However, the main expected contribution of analytical tools such as FEA Software and LAB MILL is to simulate in the design phase what will happen in real when carrying out the production scale trial. In this regard, the results obtained were very good.

As an example, Figures 21 and 22 show the bar nose formation after the leader pass in two situations: FEA simulation and during the second hot trial. We can observe that the behavior of the bar nose in both cases is very similar. Thereby, FEA simulation predicted correctly what would happen.

Figure 21. Bar nose formation after leader pass in groove E - FEA simulation

Figure 22. Bar nodr formation after leader pass in groove E – Second hot trial

Another example of comparing the accuracy between FEA simulation, reduce scale lead trials in Lab Mill and the hot mill trial is the lock formation after the last pass, which we can see in figures 23, 24 and 25.

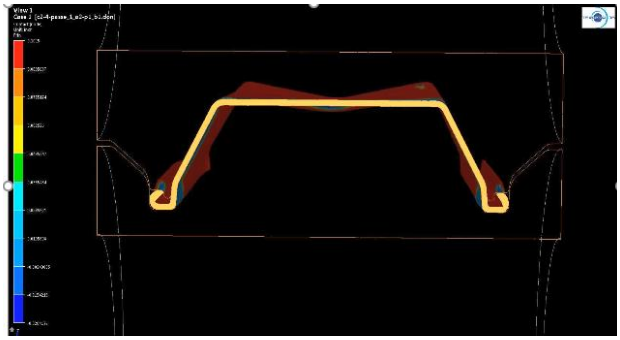


Figure 23. Lock formation after last pass – FEA Simulation

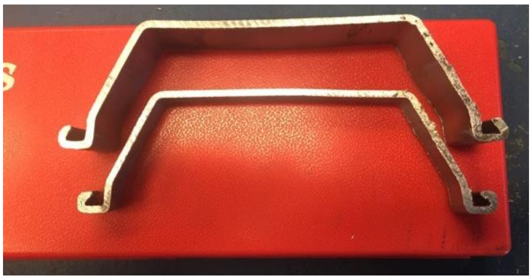


Figure 24. Lock formation after last pass – Lab Mill

Figure 25. Lock formation after last pass – hot mill trial

4 CONCLUSIONS

The main contribution of the use of analytical tools such as FEA software and reduced scale simulators such as LAB Mill in the technical evaluation of roll pass design projects of asymmetric and complex products is the financial and time saving. You can go to the hot mill trial stage with greater potential of success already in the first attempt.

It is a great achievement to be able to develop a product as complex as the EPG 600 in so few trials. The use of these analytical tools was major in this development.

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