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A Pilot Rolling Mill Designed for High Strength Steels

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Abstract. High strength steels, such as austenitic stainless steel, Transformation Induced Plasticity (TRIP) steel and silicon steel, have significant work hardening during cold rolling, which in turn induces a quickly increased rolling force. Tension plays a very important role in the reduction of the rolling force. However, coiler tension control system used in the classic experimental rolling mill requires long-scale strip, which cannot be satisfied for most experimental cases. To overcome this drawback, a new pilot rolling mill has been developed. The horizontally located hydraulic cylinders and clamps have been used to apply tension to the rolled short-scale strip. With this rolling mill, the austenitic stainless steel strip, TRIP steel strip and other high strength strips have been studied.

Introduction

Tension is one of the most important parameters for cold strip rolling, especially for cold rolling of high strength steels. Tension can significantly reduce the rolling force, and then increase the maximum thickness reduction. In the classic experimental rolling mill, coilers have been widely used to apply tension to the strip. There are two major drawbacks for the coiler tension system: (1) Long scale strip in the form of coil has to be used. However, for some experimental cases, such as rolling of newly developed materials, coil is not available. (2) A complicated tension control system is needed. In order to overcome these drawbacks, a pilot cold rolling mill with horizontally located hydraulic tension systems has been developed. This rolling mill has been successfully used in the researches of high strength steels, such as austenitic stainless steel and TRIP steel.

Experimental Procedures

The schematic of the developed pilot rolling mill is shown in Fig. 1. A four-high reverse rolling mill has been used. Roll gap is controlled by the electric screw down and hydraulic cylinder [1, 2]. The detailed parameters of this mill are listed in Table 1. Two horizontally located hydraulic cylinders with two clamps have been installed at the entry and exit sides of the mill respectively. The clamps are designed to grip the ends of the strip. Therefore, tension can be implemented by controlling the movement of the clamps.

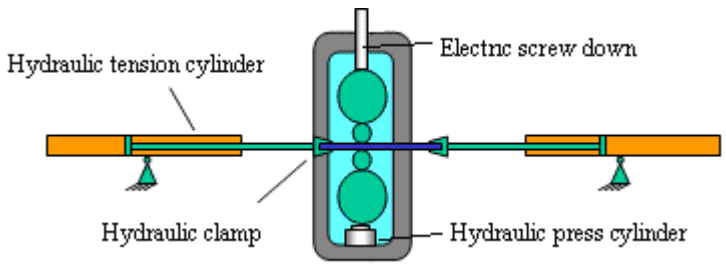

Fig. 1 Schematic of the developed pilot rolling mill

Table 1 Parameters of the pilot rolling mill

Max. rolling force [kN] (For different work roll diameter) [kN]	2500,2000,1200
Max. rolling torque [kN.m]	60
Max. tension [kN]	120
Max. rolling speed [m/s]	0.24
Work roll diameter [mm]	200~185, 150~140, 110~100
Backup roll diameter [mm]	550 ~500

The whole automation control system for this pilot cold rolling mill is composed of basic automation system, process control system and human machine interface (HMI) system[3], as shown in Fig. 2.

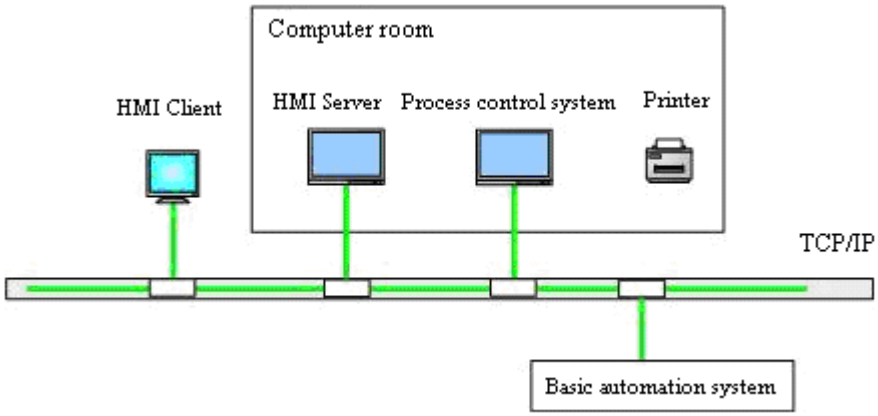

Fig. 2 Sketch of automation control system

At the beginning of experiment, one side of the strip is first gripped by the entry-side clamp and then threaded through the roll gap by moving forward the piston of the entry-side hydraulic cylinder. After another side of the strip is griped by the exit-side clamp, the roll gap will be adjusted to the setup value and rolling starts. Subsequently the tension control and roll speed control are activated. Two sensors have been installed for each hydraulic cylinder. One is the hydraulic press sensor. The other is the position sensor. The former is used to control the tension and the latter is used for the position control. The multi-pass rolling experiments can be conducted in this rolling mill. After the previous rolling pass has been completed, the roll gap and tension are re-setup and the rolls reversely rotate to give a new rolling pass.

Practical Applications

High strength steels, such as austenitic stainless steel and TRIP steel, have been studied using the developed pilot rolling mill. Table 2 shows the experimental results of the austenitic stainless steel 304 strip and Table 3 gives the experimental results of the TRIP steel strip. With this actual data, resistance-to-deformation is calculated by matching the measured rolling force. During calculation, the friction coefficient value is decided by the model of Eq. 1.

$$f = b_0 + b_1 \cdot h + b_2 \cdot \varepsilon \,, \tag{1}$$

where f is the friction coefficient, h is the thickness after one pass, ε is the reduction of one pass, b_0, b_1 and b_2 are the model parameters.

Then resistance-to-deformation model can be regressed with model format as Eq. 2.

$$\sigma_s = a_0(a_1 + e)^{a_2}, \tag{2}$$

where σ_s is the resistance-to-deformation stress, e is the accumulated strain, a_0, a_1 and a_2 are the model parameters.

Table 2 Austenitic stainless steel 304 rolling process actual data

Mill Information:									
Work roll diameter[mm]		Backup roll diameter[mm]							
149.0		550.0							
PDI Information:									
ID		Steel grade	Material Size[mm]			Production size[mm]			
			Thickness	Width	Length	Thickness	Width	Length	
1100000012		304	3.000	250.00	300.00	1.352	250.00	665.7	
Pass actual data:									
Pass Number [-]	Roll gap [mm]	Rolling force [kN]	Entry thickness [mm]	Exit thickness [mm]	Reduction [%]	Entry Tension [kN]	Exit Tension [kN]	Rolling speed [m/s]	Motor power [kW]
1	2.653	930.42	3.000	2.656	11.465	48.80	42.52	0.093	7.209
2	2.443	943.58	2.656	2.501	5.835	53.50	30.52	-0.108	2.360
3	2.353	945.27	2.501	2.383	4.721	49.09	42.92	0.112	4.692
4	2.208	973.08	2.383	2.285	4.099	53.44	30.83	-0.110	1.664
5	2.168	949.78	2.285	2.205	3.506	49.07	42.94	0.102	3.931
6	2.064	964.53	2.205	2.149	2.567	53.36	30.51	-0.092	0.593
……									
33	1.089	1203.27	1.363	1.352	0.822	79.52	80.41	0.103	2.554

Table 3 TRIP steel rolling process actual data

Mill Information:									
Work roll diameter[mm]		Backup roll diameter[mm]							
200.0		550.0							
PDI Information:									
ID		Steel grade	Material Size[mm]			Production size[mm]			
			Thickness	Width	Length	Thickness	Width	Length	
090617-TRIP2		TRIP	5.350	150.00	775.00	1.878	150.00	2208.2	
Pass actual data:									
Pass Number [-]	Roll gap [mm]	Rolling force [kN]	Entry thickness [mm]	Exit thickness [mm]	Reduction [%]	Entry Tension [kN]	Exit Tension [kN]	Rolling speed [m/s]	Motor power [kW]
1	3.96	1385.6	5.350	4.589	14.23	103.28	97.83	0.037	4.813
2	3.30	1391.5	4.589	3.999	12.86	117.70	94.31	-0.037	5.245
3	2.78	1406.8	3.999	3.494	12.63	99.58	95.35	0.036	3.867
4	2.22	1447.0	3.494	3.035	13.14	117.86	93.93	-0.036	4.898
5	1.84	1464.5	3.035	2.678	11.73	92.95	84.25	0.036	3.462
6	1.41	1512.1	2.678	2.375	11.33	95.42	75.34	-0.037	3.849
7	1.08	1581.1	2.375	2.104	11.43	76.30	72.38	0.037	3.020
8	0.62	1735.9	2.104	1.878	10.74	78.43	64.59	-0.037	3.274

Experimental actual data and regression results for the stainless steel 304 and the TRIP steel are depicted in Fig. 3 and Fig. 4, respectively.

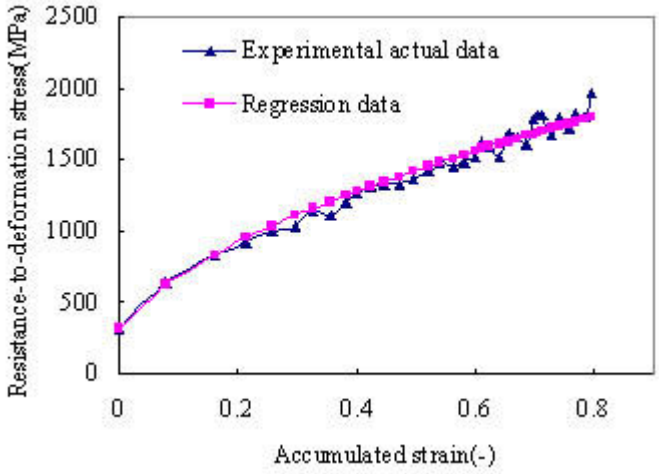

Fig. 3 Stainless steel 304 resistance-to-deformation curve

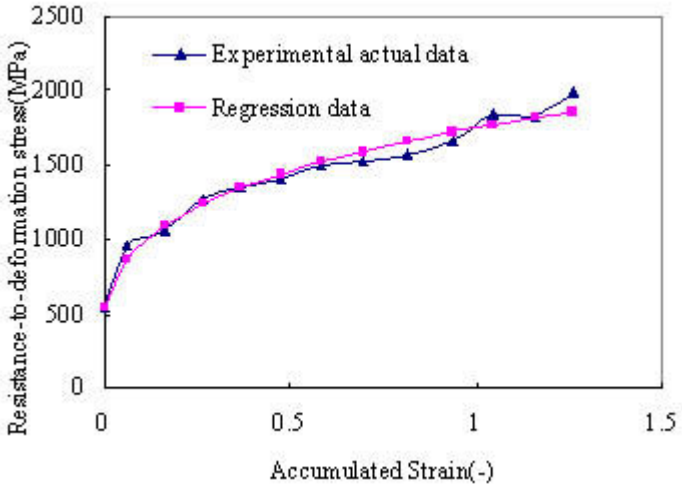

Fig. 4 TRIP steel resistance-to-deformation curve

Conclusions

A new pilot cold rolling mill has been developed for researches of high strength steels. The horizontally located hydraulic cylinders and clamps are used to apply the tension to the rolled strip. Automation control system has been developed to implement the stable tension control. Stainless steel 304 and TRIP steel have been studied with this pilot cold rolling mill. The experimental data, such as roll gap, rolling force and roll speed, are measured and the resistance-to-deformation model is regressed.

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