NON-DESTRUCTIVE HOT ROLLING SCHEDULES DEVELOPMENT FOR LOW Mn/S RATIO 1008 STEEL

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Abstract

Strip destruction in edge areas occurs during industrial hot rolling of low-manganese (Mn/S = 4.5-5) 1008 steel on continuous mill 2000. It is caused by detrimental sulfur effect on metal ductility in the certain temperature and strain range. Found that the failure reasons for 1008 steel during hot rolling are edge areas rolling at the failure ductility temperature range and cast strainless structure availability in edge areas at the first rolling passes. Integrated approach, based on a mathematical and physical simulation combination, was offered to hot ductility investigation and non-destructive hot rolling schedules development. Mathematical simulation of continuous cast billet hot rolling was carried in Deform-3D program. Physical simulation of metal thermomechanical treatment was made by Gleeble-3800. The proposed integrated approach was allowed establish the conditions to achieve maximum metal plasticity in edge areas. Developed rolling schedules successfully realized and introduced on industrial environments.

Keywords: hot ductility failure, hot rolling, mathematical and physical simulation, tension-compression technique

1. MAIN TEXT

It is known that one of the causes of steel plasticity failures in the certain temperature and strain range is excessive sulfur content. It leads to destruction of the metal during rolling, Fig.1. One way to reduce negative impact of sulfur is the addition of manganese in steel. The optimal ratio of manganese to sulfur is typically Mn/S = 30-40. As a result of the doping probability of occurrence failure ductility is reduced [1, 2, 3, 4].

Extensive practical interest is the manganese content decrease in steel to values Mn/S = 3,5-5, it can significantly reduce the rolled cost. Thus, for processing these steels requires adjustment of existing rolling schedules to prevent the destruction of the metal.

The purpose of this study is to develop non-destructive hot rolling schedules for low ratio Mn/S = 3,5-5 1008 steel on continuous mill 2000. The main reasons for metal fracture considered strip edge region rolling in the temperature range of failure ductility, and the presence of a cast undeformed structure in these areas at the first rolling passes. To solve this problem, comprehensive approach was proposed, based on a combination of mathematical and physical simulation of hot rolling. Such approach allows to establish edge region deformation schedules and to evaluate strip edge region ductility.

Mathematical simulation the entire cycle of continuous cast billet hot rolling was made in Deform-3D program. Physical simulation was performed on Gleeble-3800 complex using "tension-compression" technique [5].

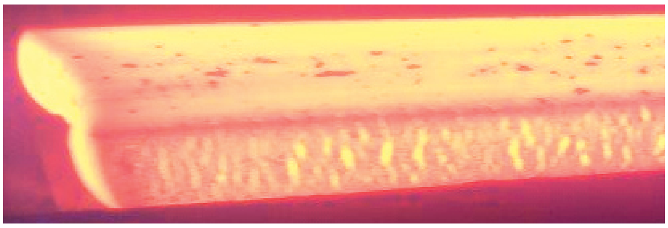
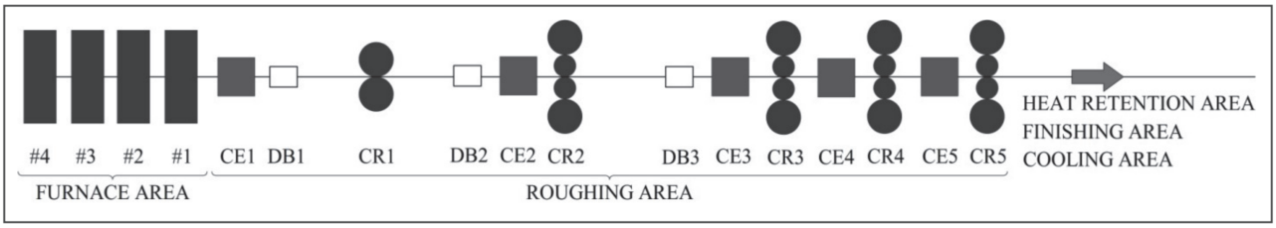


Fig. 1 The fracture behavior low Mn/S = 3,5-5 1008 steel during hot rolling on mill 2000

Mathematical simulation of hot rolling using Deform-3D program

To solve temperature and deformation problem, to calculate temperature fields and stress-strain state during hot rolling, rolling mill 2000 computer model in Deform-3D program was established. The model considers roughing and finishing stand parameters, and heat retention area parameters. Equipment arrangement of mill 2000 is shown on **Fig. 2**.



CE - Continuous Edger; DB - Descale Box; CR - Continuous Rougher

Fig. 2 The rolling mill 2000 scheme

Rolling schedules at which strip surface temperature before CR1 stand is 1050, 1100 and 1150 °C was investigated. Temperature model calibration was performed based on experimental data obtained on mill 2000. To solve deformation problem of rolling in the Deform-3D program were set the following parameters: model of deformable material - rigid-hardening, whose properties were assigned flow stress curves; mill rolls model - rigid.

The rheological 1008 steel properties, integrated into the model were obtained by uniaxial compression tests for given temperature and deformation parameters on Gleeble complex. Zibel friction index between mill rolls and rolled strip was taken μ = 0,8 [6]. Thermo-physical 1008 steel properties were set as temperature function from the Deform library data. To estimate metal softening during pauses between deformation due to stress relaxation evaluated by AusEvolPro program developed in the laboratory "Research and metal structure and properties simulation " [7]. At Deform program modeling metals softening were considered by accumulated effective strain values zeroing. Solution of the problem is calculated metal temperatures, effective strains and effective strain rates at various stages of rolling (**Fig. 3, 4**).

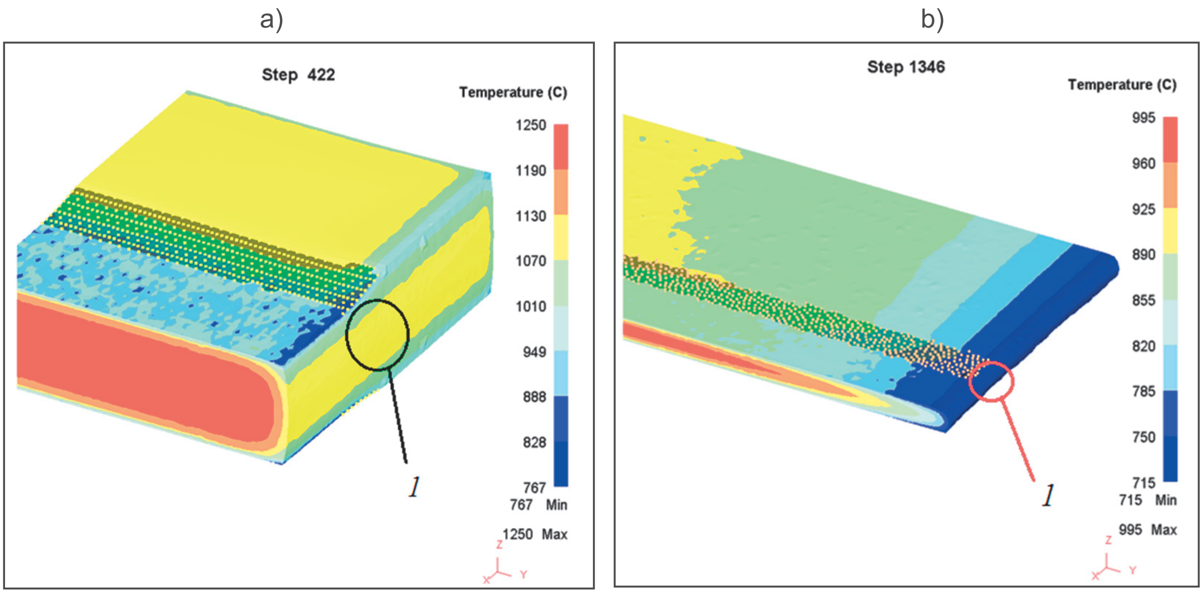


Fig. 3 Temperature distribution fields in the strip during rolling in: a) CR1 stand in roughing area; b) CR12 stand in finishing area; 1 - the investigated strip area

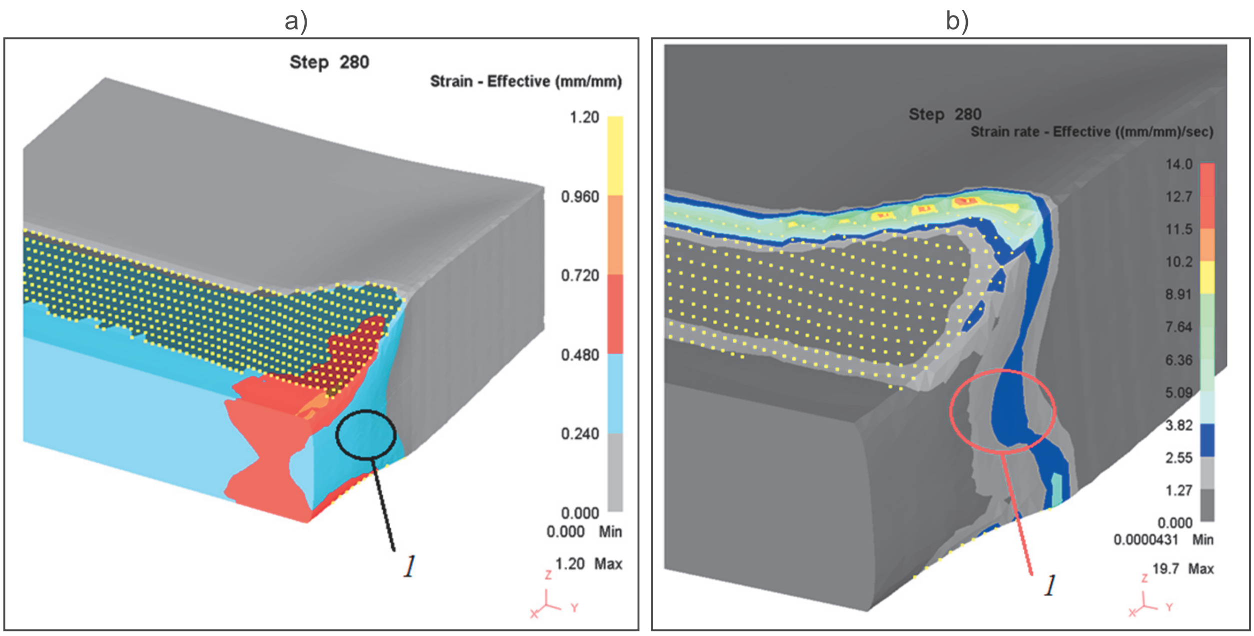


Fig. 4 Distribution fields in the strip during rolling in CR1 stand in roughing area of: a) effective strain; b) effective strain rate; 1 - the investigated strip area

Roughing and finishing rolling simulation results for 1008 steel at various technological schedules are shown in **Table 1, 2**. In **Table 1** shows the calculated temperature for the central part of the edge region, and thus average and normal operation descaling №2, 3 were regarded. Descaling operation mode on the mill can be controlled by changing water flow and quantity control of involved sections.

Table 1 Edge region temperature calculation results during rough rolling made by Deform-3D program

Rolling schedules	Temperature, °C									
	CE1	CR1	TR2	CR2	TR3	CR3	TR4	CR4	TR5	CR5
T_1=1050 °C	1010	1038[1]	1062	957[1]	1018	924[1]	1005	985	1024	1008
		1039[2]		1000[2]		990[2]				
T_1=1100 °C	1060	1097[1]	1107	969[1]	1064	953[1]	1048	1045	1030	1046
		1097[2]		1035[2]		1038[2]				
T_1=1150 °C	1110	1144[1]	1140	1017[1]	1113	1004[1]	1093	1107	1085	1067
		1146[2]		1091[2]		1080[2]				

1 - normal operation of descaling box

2 - average operation of descaling box

TR# - transportation to the stand number #

Table 2 Edge region temperature calculation results during finish rolling made by Deform-3D program

Rolling schedules	Temperature, °C				
	CF6	CF7	CF8	CF9	CF10
T_1=1050 °C	815	774	755	734	709
T_1=1100 °C	821	783	751	730	702
T_1=1150 °C	828	768	740	718	686

In **Table 3** shows the calculated maximum effective strain and average effective strain rate in the edge region of strip during rough and finish rolling.

Table 3 Maximum effective strain and average effective strain rate calculation results during rolling made by Deform-3D program

Stress-strain state parameters in the edge region	Stand number										
	Roughing area						Finishing area				
	CE1	CR1	CR2	CR3	CR4	CR5	CF6	CF7	CF8	CF9	CF 10
Maximum effective strain, relative units	0,05	0,18	0,5	0,71	0,52	0,97	0,69	0,87	0,84	0,53	0,61
Average effective strain rate, s^{-1}	1,25	1,44	3	2,6	4,5	10	8	11	24	34	46

According to proposed earlier hypothesis about the causes of failure, associated with poor deformed of the cast slab structure in the lateral edge of the strip, study of redaction and rolls profiling influence on effective strain were performed. In **Fig. 5** shows the effective strain field at using different rolls profiling of continuous Edger stand.

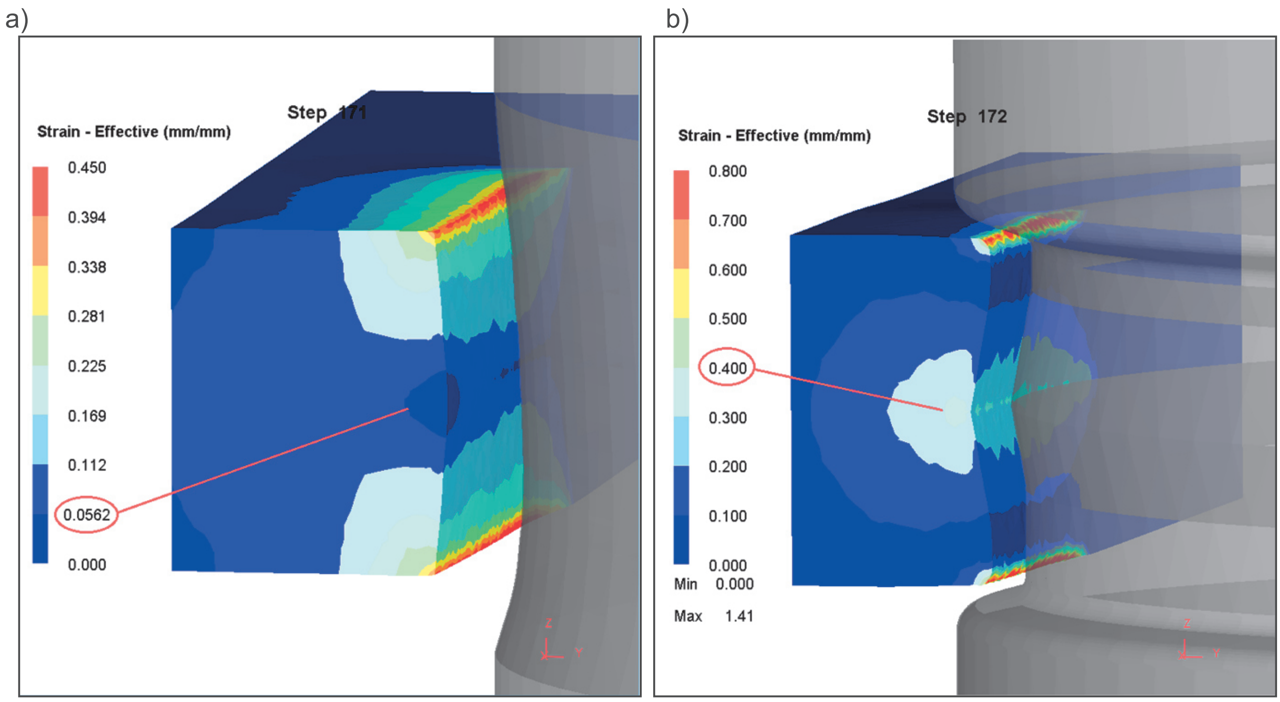


Fig. 5 Effective strain field distribution during deformation at continuous Edger stand #1 with: a) concave profiling; b) convex profiling

On **Fig. 5** shows that, by using concave profiling rollers, central layers of lateral edge were almost not deformed (**Fig. 5a**), in contrast to the use convex profiling (**Fig. 5b**), in this case the central layers of lateral edge deformation is more intense. However, in practice, undesirable to use convex profiling rolls because occurrence additional hump on roll thickness, which can lead to uneven strain during further rolling.

2. HOT ROLLING PHYSICAL SIMULATION

Physical simulation of rolling was performed on a Pocket Jaw unit of Gleeble-3800 complex. Investigations have been performed on cylindrical samples with the working part length 10 mm and diameter 6 mm. In the simulation deformation tension-compression technique was used. According this technique plastic deformation processes physical simulation with designed specimen single stage deformation ε is divided by two deformations: tension with ε/2 and compression with ε/2 (Eq. 1):

$$\varepsilon_t = 2\ln\left(\frac{d_0}{d_0-\Delta d}\right), \qquad \varepsilon_c = 2\ln\left(\frac{d_0-\Delta d}{(d_0-\Delta d)+\Delta d}\right), \tag{1}$$

where ε_t - true strain during tension; ε_c - true strain during compression; d_0 - initial sample diameter, mm; Δd - sample diameter varying, mm.

The temperature control performed using the control thermocouple welded to the central part of the sample. In the same section by means of lateral deformation sensor deformation was measured. In the simulation deformation on Gleeble-3800 complex was used calculated in Deform-3D temperatures, effective strain and effective strain rate (**Table 1, 2, 3**) for the edge region of the strip. Plasticity was evaluated by measuring percentage sample reduction in the neck Ψ.

2.1. Effect of pre-strain on cast metal plasticity in continuous Edger stand #1

The main task of this work part is the study of deformation influence during cast slab rolling in the continuous Edger stand #1 on the metal plasticity in the edge region in subsequent continuous rough stand #1. On Gleeble-3800 complex strain conditions for strip edge region were reproduced, which comprises sample heating up to 1250 °C and holding 60 s for austenitization, cooling to deformation temperature in continuous Edger stand #1 and further cooling by descale box #1 and sample stretching to fracture. According to tests neck percentage reduction dependence on the strain in continuous Edger stand #1 for three temperature modes rolling, which differ temperature T1, were determined (**Fig. 6**).

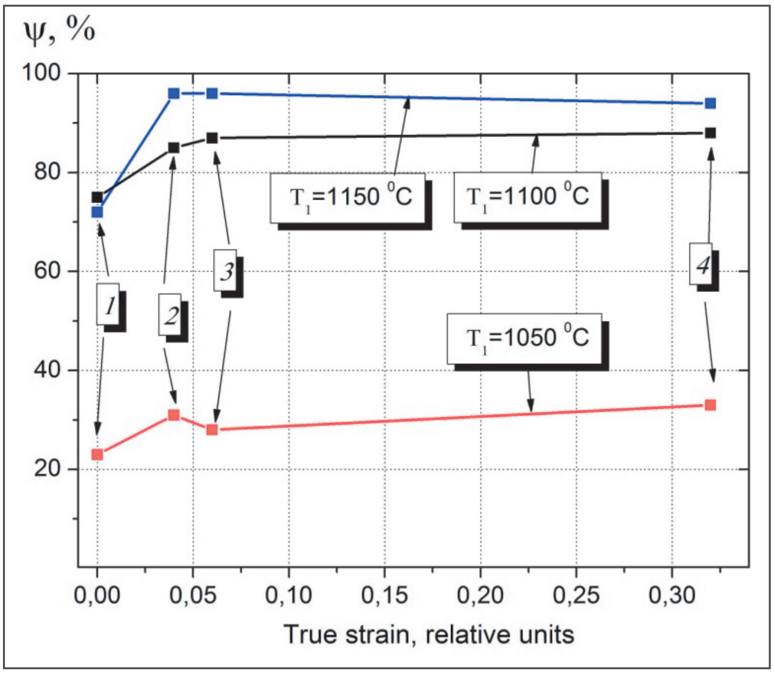


Fig. 6 Metal plasticity dependence in edge strip region on continuous Edger stand #1 pre-strain 1 - plasticity without deformation; 2, 3 - using a concave rolls profiling, 4 - using convex rolls profiling

In **Fig. 6** shows that the cast metal ductility is directly dependent on the selected rolling mode. When rolling at T1 = 1050 °C, plasticity is only ψ = 23%, but at T1 = 1100 °C and T1 = 1150 °C plasticity is ψ = 72 % and 78 %, respectively. On **Fig. 6** shows that strain increasing during rolling on mode T1 = 1050 °C has no effect almost on metal plasticity, which remains relatively low. By rolling on modes T1 = 1100 °C and T1 = 1150 °C slight deformation 4 %, achieved by using a concave profiling can increase the ductility up to 85 - 96 %, with a further strain increase does not lead to a to an appreciable increase in plasticity.

2.2. Determination of the metal plasticity in the edge strip region during roughing rolling

In **Fig. 7** describes the general test scheme to plasticity determine prior to each roughing area stands on mill 2000 for three modes which differ rolling temperatures (**Table 1**). **Fig. 7** shows the dependence of the relative neck constriction on pass number at various descaling box #2, 3 working conditions. Cooling intensity reducing at descaling box #2, 3 (**Table 1**) can significantly increase plasticity of the metal in possible destruction areas.

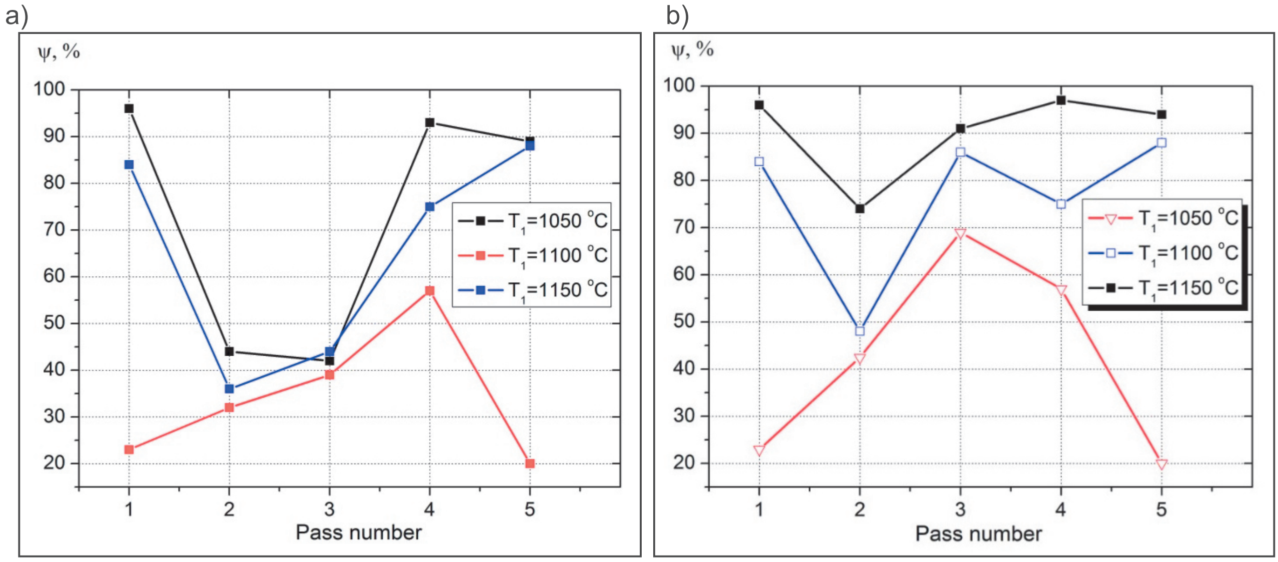


Fig. 7 Dependence relative neck reduction on pass number at roughing area rolling: a) normal descaling box #2, 3 operation; b) average descaling box #2, 3 operation

Plasticity 1008 steel at the edge strip area during roughing rolling is relatively high (ψ = 70-96 %) and increases with the rolling temperature decreases (**Fig. 7**), which caused by the release from temperature range of plasticity failure, which occurs at T = 850-1050 °C.

CONCLUSIONS

- A universal technique which allows using the serial combination of physical and mathematical simulation to reproduce the temperature-deformation processing conditions at specified areas of various metal forming processes was developed.
- Proved the possibility of practical use method by hot ductility of 1008 steel ratio Mn/S=3.5-5 investigating during rolling on continuous mill 2000.
- It was shown that plasticity failure of 1008 steel occurs at roughing rolling area. Determining factors influencing on destruction of metal are cooling intensity at descaling box #2, 3 and temperature rolling conditions.
- Concave continuous Edger stand #1profiling provides conditions for increasing of metal plasticity in the edge strip area during the deformation in the subsequent stand, only when the temperature of metal before the entrance to the continuous rough stand #1 is not less than 1100 °C.

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