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Research of edge defect formation in plate rolling by finite element method

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ABSTRACT

For hot-rolled flat products major losses of steel are due to surface defects, which are caused by the quality of an incoming continuous cast slab. Each typical surface defect of a continuous cast slab if not detected and eliminated transforms into a surface defect of a rolled plate. One of the most critical problems of hot rolled plates is connected with the longitudinal surface cracks located at the distance up to 80 mm from the edges. This study covers the research and simulation of transformation of surface cracks into the edge defects of the hot-rolled plate by finite element method. It is shown that the mechanism of crack movement during plate rolling comes from inclination of front and tail faces of slab due to temperature gradient between top and bottom surfaces. To reduce the possibility of corner crack formation it is proposed to increase the temperature of the edge zone of the slab due to the rounding of edges or by induction heating. The results of the study will be useful for material saving during plate rolling.

1. Introduction

Competitive capacity is the main characteristic of a product and it is defined by the relation between its consumer properties and price. Due to the global drop in demand for steel the competitive struggle is getting more severe. Therefore the basic challenge for metallurgical enterprises is to decrease production-related costs along with the improved output quality.

For hot-rolled flat products major losses of steel are due to surface defects, which are caused by the quality of an incoming continuous cast slab. Surface defects appear in continuous cast slabs due to a wide range of reasons which can combine and aggravate each other. Each typical surface defect of a continuous cast slab if not detected and eliminated transforms into a surface defect of a rolled strip or plate which will then be sorted out as a non-compliant product. The most critical problem for rolled plates correlates to propagation of longitudinal and transverse surface cracks located along the length of the rolled product at the distance up to 80 mm from the edges (Figs. 1 and 2). These data were obtained from plate mill 5000 for a period of 8 months. The crack depth can be absolutely different, within the range from 0.1 to 2.0 mm depending on the depth in the moment of their formation.

A longitudinal cracks are formed in a crystallizing shell of a slab due to differential shrinkage caused by varying rate of thermal rejection along the perimeter of the shell. The probability of hot cracks formation increases if overheated steel is being cast with a high speed of strand withdrawal, or if a casting powder with improper viscosity characteristics is used. Transverse cracks are formed due to tensile stresses occurring during strand withdrawal slowdown. Tensile stresses can be caused by utilization of improper casting powder, misalignment of roller segments of the caster, uneven secondary cooling. Crack susceptibility increases in case of defects along oscillation marks (slag inclusions, rippled surface from oscillation marks).

Chemical composition of steel can cause surface cracking as well. The analysis of a slab surface shows that there is dependence between increased number of cracks per unit of area and degree of their intensity and increased content of carbon within the range from 0.07% to 0.20%. Furthermore, the number of surface cracks increases due to higher mass concentration of manganese. But the most critical chemical element for continuous casting is niobium (Nb). There are many works that prove that even a small amount of Nb added into steel causes surface cracking of continuous cast slabs. A detailed study of the mechanism of crack formation during continuous casting of niobium-containing steels is researched by Hannerz (1985). According to the results of the studies, crack formation is mainly caused by stresses occurring during withdrawal of a strand. During this process cracks appear in the areas with reduced plasticity. For rectangular cross-section of slabs the most

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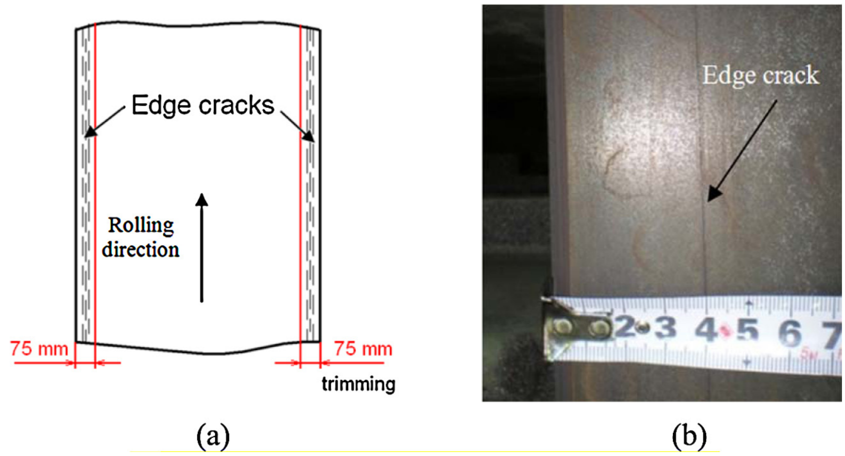

Fig. 1. General view of edge cracks (a) and practical data (b).

intensive cooling of solidified steel is performed in edge zones and corners of a strand. Therefore, plasticity of steel in these areas is significantly worse than in the areas of wide faces. So, the main reason for formation of surface cracks is temperature conditions, the second reason is deep folds which occur due to reciprocated mold operating.

The defects on the surface of a continuous cast slab are concentrators of stresses during the process of hot strip and plate rolling; this results in developing of the existing cracks and formation of new ones. Consequently, we have more defects on the surface of finished rolled products.

Many works studied some cases of deformation behavior on edge defects by using finite element method (FEM). Takashi et al. (2003) presented the analysis of the character of plate surface defects deformation. During modeling process of hot rolling a V-shaped defect was analyzed. The results of the numerical simulation are demonstrated that increased reduction leads to defect opening during rolling of V-shaped defects. Gulova et al. (2008) researched the defects influence on final quality of rolled flat products. Artificial defects of V- and U-score types were applied to a "slab" having different sizes, designs and locations. Formation of primary defects was observed with increasing of a relative amount of deformation by 50%, where overlaps and scratches were observed. Ervasti and Ståhlberg (2000) and Yu (2010) presented the research of the transformation of slab surface cracks during hot rolling with the use of DYNA software based on FEM. Influence of three rolling modes on transverse cracks was analyzed. It was found out that with the increase of deformation fractioning the angle of crack opening or their width significantly increased, the final depth of a crack therewith remained almost the same. Kainz et al. (2008) and Pesin et al. (2010a,b) performed systematic forming simulations of the development of initial slab corner cracks during hot roughing and finishing mill passes utilizing the finite element package Deform-3D. The numerical results described the morphological changes of such already existing corner cracks. Chun and Park (2007) observed the effective method to decrease edge defect of stainless steel in hot strip mill. Deformation behaviors of the slab edge in roughing rolling process were analyzed by the rigid-plastic finite element method. They guessed that the edge defects depended mostly on the edge bulging generated by the difference of metal flow between contact area and noncontact area due to rolling. Luo et al. (2014) investigated the morphology of surface crack and microstructure evolution in the rolling process. It was found that the microstructures around cracks with the different depth are almost identical, without direct correlation with the initial crack depth.

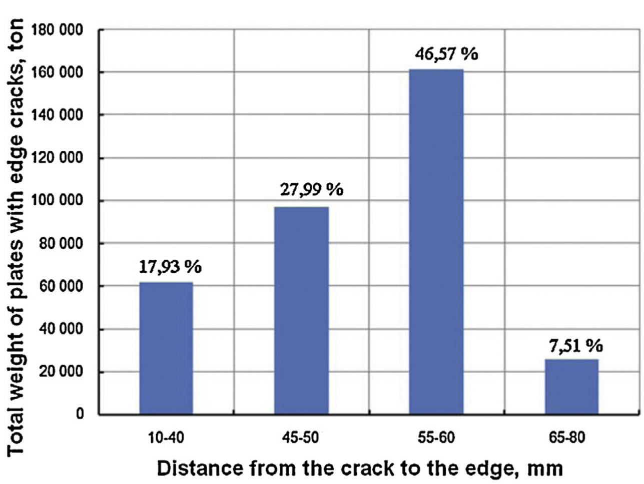

Fig. 2. Location of edge cracks (practical data).

In this study our focus is the finite element modeling of the evolution of the existing slab surface cracks during hot plate rolling. Numerical modeling and study of principal regularities of transformation of surface cracks in a slab into surface defects of a rolled plate was examined to evaluate optimum rolling conditions. The goal of the research is to define the reason of the edge cracks formation during plate rolling. The results of the study will be useful for material saving during plate rolling.

2. Finite element simulation of edge defect formation by means of DEFORM package

2.1. Deformation behavior of slab corner crack

During mathematical modeling of a hot rolling process, the concast slabs with surface cracks are considered a material under deformation (Pesin et al., 2010a,b). Thus it is the researcher who sets initial forms, location and dimensions of the defects. For modeling of this process it is important to set up the problem and to determine boundary conditions. Besides the experimental data should prove the result.

To simulate the edge defect formation during hot plate rolling, the commercial finite element package Deform 3D (SFTC, USA) is used. The conditions for the modeling of hot rolling of slabs with surface cracks are the following: evolution of microstructure in steel is not considered; the rolls are incompressible (absolutely