Effective Rough Rolling of Low-Alloy Steel

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Abstract—The behavior of surface defects in continuous-cast slabs is investigated during rough rolling. A model of the change in defect shape is developed, and recommendations are made regarding the prevention of crack motion toward the strip axis.

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In processing continuous-cast low-alloy steel slab, great attention is paid to surface cracks. As a rule, such cracks are not closed in hot rolling but move from the edges of the strip to the middle, with corresponding increase in the trimming required and considerable economic losses. Accordingly, in the present work, we investigate defect behavior in rough rolling on the basis of a mathematical model of their shape variation and develop recommendations regarding the prevention of crack motion in the strip.

The deformation of slabs with a transverse crack at the lateral face is simulated by the finite-element method, using phenomenological failure theory \cite{1}. Niobium-bearing steel is chosen as the basic material. Its resistance to deformation is described using a regression model based on plastometric data \cite{2}. The slab temperature is assumed to be constant and distributed uniformly over the metal volume. The frictional coefficient in hot rolling is determined by the Bakhtinov–Shternov formula.

The dimensions of the transverse crack are shown in Fig. 1, along with the proposed division into finite elements. To study the stress–strain state of the crack in steady rolling, we assume that it is in the middle of the slab. Since the crack is a stress concentrator, the size of the elements in this region is minimal.

The influence of the shape of the tool on the transition of the metal from the lateral faces of the slab to the basic surfaces is studied by comparative analysis of roller operation. The slab is deformed in two passes in vertical rollers of a coarse scale breaker and horizontal rollers of a two-roller cell. Two cases are considered: reduction of the slab in vertical rollers with a smooth barrel and in grooved rollers (Fig. 2). The rolling conditions in the horizontal pass are the same in both cases.

The vertical displacement field is shown in Fig. 3 in the cases where the slab passes through vertical rollers with a smooth barrel and rollers with a box groove that has a convex floor. It follows from Fig. 3 that the use of grooved rollers reduces the height of the buildup by 15–20\% and shifts it further away from the lateral edge. The lateral wall of the slab becomes somewhat concave. Therefore, in horizontal rollers, the expansion will be considerably less than in rollers with a smooth barrel.

The change in slab shape on reduction successively in vertical and horizontal rollers is shown in Fig. 4 for the two cases considered. The displacement of points of the finite elements in deformation is determined so as to permit quantitative estimation of the transition of metal from the lateral furnaces.

When the slab is reduced in vertical rollers with a smooth barrel (Fig. 4a), considerable buildup is formed near the edges. The metal is mainly shifted in the vertical direction (point \(A_v\)). In the horizontal rollers, the slab is considerably expanded, and the metal passes from the lateral faces to the contact surface with the horizontal rollers (point \(A_h\)). In this case, the metal travels more than 9 mm from each lateral face.

When using grooved rollers (Fig. 4b), the buildup is shifted to the middle of the slab. The height is considerably less than for rollers with a smooth barrel. The vertical motion of the metal from the lateral faces (point \(A_v\)) is slight, i.e., the groove tends to retain the

\begin{figure}[ht]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{Dimensions of transverse crack and the proposed division into finite elements.}
\end{figure}

\textsuperscript{1} O.N. Sychev and A.A. Skrylev participated in this work.
defects near the edges. In the horizontal rollers, the broadening of the slab is considerably less (3 mm, point \( A_h \)) than in the first case.

Thus, comparative analysis of transverse slab deformations shows that grooved rollers tend to retain the surface defects at the lateral faces, on account of the reduced broadening in subsequent horizontal passes.

Reduction conditions in horizontal rollers intended to limit defect motion are employed in the roughing group of the 2000 broad-strip hot-rolling mill. Simulation of hot rolling in the finishing group of the mill permits quantitative evaluation of the effectiveness of this approach. The table presents the initial conditions for the simulation with two distributions of the reduction.

Numerical simulation yields the stress and strain fields and the probability of crack formation in hot rolling using the Cockroft–Latham criterion. According to this criterion, failure occurs when the accumulated energy exceeds the tensile strength. This criterion results in satisfactory prediction of the failure location under tensile stress.

In Fig. 5a, the probability of crack formation after slab reduction in the vertical rollers of a coarse scale breaker is plotted. In the region of the buildup, where tensile stress acts, the probability of crack formation is no more than 14% according to the Cockroft–Latham criterion. For the two-roller cell, tensile stress acts in the zones of front and rear deformation outside of the contact area and also at the slab’s lateral surface. The maximum tensile stress appears near the edge. Thus, on account of the change in shape of the strip during successive reduction in vertical and horizontal rollers, an unfavorable stress state is created in these areas. In the presence of stress concentrators (local defects and non-metallic inclusions), cracks may form.

In the second case, with reduction in the two-roller cell by 28 mm, rather than 45 mm, the tensile stress is 11.6% less. In addition, with smaller reduction, the workability of the metal deteriorates over the thickness, which increases the risk of internal cracks and cavities.

According to the simulation of rolling in a two-roller cell (Fig. 5b), the probability of crack formation near the edge is 33.1% in the first case and 27.5% in the second. Analysis of the data in subsequent passes shows that, with increase in the total strain, the probability of crack formation increases, while the maximum values are close to the edges.