Abstract:

This paper describes state-of-the-art nondestructive testing techniques developed at JFE steel for the hot-rolling of steel sheets. The following are reported: (1) A technique for high-resolution ultrasonic detection of internal flaws in deep positions through a combination of focused beam testing and a synthetic aperture method; (2) A technique for detecting surface flaws with a high signal-to-noise ratio using a newly developed broad-bandwidth surface wave probe; (3) An intelligible display technique for mapping the flaws detected in the surface testing. The development of these techniques has made it possible to thoroughly evaluate the soundness of work-rolls. The techniques are now being applied to actual production processes to maintain a high surface quality for sheet steel and to prevent work-roll troubles caused by internal flaws and surface flaws.

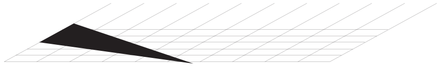
1. Introduction

Work rolls are repeatedly subjected to high stress while being used for the hot-rolling of steel sheets. Surface flaws are occasionally formed in work-rolls used for rolling under abnormal rolling conditions. When a surface flaw remaining in a work-roll is repeatedly subjected to high stress, it can expand into a large crack and thereby cause problems such as roll spalling and marking on the rolled strip. To cope with the wear and roughening of the work-roll, the surface of the work-roll is ground by a grinder after rolling a prescribed length of strip. Once re-profiled by the grinder, the surface of the work-roll is tested by a surface flaw detector. If a surface flaw is detected, the surface is re-ground until the surface flaw is removed. In addition, small internal cracks can cause problems. When such a crack appears around a small internal flaw, it may grow into a big crack with repeated high stress.

The only reliable way to maintain the surface quality of a steel sheet and to prevent the work-roll troubles induced by surface flaws and internal flaws is to use the work-roll with no surface flaw and no internal flaw. It needs the detection of both surface flaws and internal flaws with high certainty. JFE has therefore developed several nondestructive testing techniques to thoroughly evaluate the soundness of work-rolls. This paper outlines the techniques developed by JFE.

2. High-resolution Ultrasonic Detection of Internal Flaws in Deep Positions by Combining Focused Beam Testing with a Synthetic Aperture Technique

A work-roll for the hot-rolling of steel sheets consists of an outer layer (a maximum of 80 mm in thickness) that comes into direct contact with the material and is now applying it for the detection of internal fl



2-dimensional scanning of the ultrasonic probe. The beam path length $W_{i,j}$ of the echo is calculated using the time difference between the surface-echo and the flaw-echo.

(3) The depth position d where the flaw is estimated to exist is calculated. Each element in the plane with the depth of d is 2-dimensionally addressed by $\mathrm{PF}_{k,l}$.

(4) Distances L between the measuring point $P_{i,j}$ and all the elements $\mathrm{PF}_{k,l}$ are calculated, and if $L=W_{i,j}$, 1(one) is added to the counter $C_{k,l}$.

(5) The procedure mentioned in (4) is executed for every measuring point $P_{i,j}$

2.3 Imaging of Internal Flaws in a Cut-out Sample Using SwiFT

Internal flaws positioned at a depth of 80 mm in a test block cut out of a large-size cast steel product were tested using SwiFT and a conventional method for immersion focused beam testing. The experiments were performed with the 50 mm-diameter focused probe with a 2 MHz frequency, with the focal point of the focused beam set to 80 mm in depth. **Figure 4** compares the image (the brightness is modulated according to the probability) of internal flaws obtained by SwiFT and a C-scan image (the brightness is modulated according to the echo amplitude) of the same internal flaws obtained using of the conventional method for immersion focused beam testing. The resolution obtained by SwiFT was superior beyond comparison. The image of the internal flaws agreed well with the metallographic image in the cross-sectional observation.

3. Roll Surface Testing Using Broad-bandwidth Surface Waves

3.1 Problems in Conventional Technique and Background for Development

The work-rolls used for hot finish rolling are usually made of high-speed tool steel and their surfaces tested by surface wave testing[3–6]. The whole surface of the work-roll (test body) is tested by scanning a surface wave probe in the axial direction of the rotating roll as shown in **Fig. 5** (in **Fig. 6** this scanning is described as a “helical scan”). The probe transmits the surface wave in the direction opposite to the rotation of the roll and receives surface flaw echoes. A water-gap method is used for the coupling between the surface wave probe and the test body[7].

In the surface testing of the work-roll, the presence of coarse grains, a rough surface, and a profusion of minute fine cracks produced in hot rolling (hereafter described as “collective fine reflectors”) produce back-scattered waves with small amplitudes. When these back-scattered waves superimpose with each other during conventional techniques, they collectively produce large amplitudes and the following problems result: (1) in some cases, the deteriorated signal-to-noise ratio of the flaw echoes makes it impossible to detect surface flaws, and (2) back-scattered waves with high amplitudes create the false appearance of flaws (false indication) where none are present.

3.2 Development of a Broad-bandwidth Surface Wave Probe with High Sensitivity

The height P_g of echoes from the collective fine reflectors in the path of ultrasound is give by

$$P_g = \sqrt{\alpha_0 \cdot \tau} \cdot \exp(-2\alpha_0 x)/x \cdots\cdots\cdots\cdots (2)$$

where, x is a distance from the probe to the reflector and α_0 is the attenuation coefficient, a value proportional to the square root of the pulse duration τ of the ultrasound$^{8)}$.

From Eq. (2), the authors see that a shortening of the pulse duration of ultrasound effectively reduces P_g. Because the reflectivity of ultrasound at a flaw is indep441]TJ-1uo ul41]TJec708tcan7gd) aw tional narrow-bandwidth probe, artificial flaws must have cross sections of at least 0.2 mm^2 to be detected. Thus, the newly developed probe can detect a flaw with a cross section three times smaller than the smallest cross section detectable by the conventional narrow-bandwidth probe.

Figure 6 shows the results of flaw detection tests with the newly developed probe and the conventional narrow-bandwidth probe installed in an automatic roll surface flaw detector, using a work-roll with a crack formed during rolling. The height of the crack echo detected with the newly developed probe was equal to that detected with the conventional probe, whereas the height of the noise detected with the newly developed probe was