

# Analysis of Surface Spalling on a First Intermediate Roll in Sendzimir Mills

Shiang-Cheng Jeng and Horng-Shing Chiou

**Abstract**—A first intermediate roll of Sendzimir mills was failure by surface spalling during operation. After analyzing by visual, stereo microscope, optical microscope, scanning electron microscope, glow-discharged spectrometer and hardness test, respectively, the results show that some voids and cracks existed on the contact surface as well as subsurface. Further examination verified inadequate hardness and inclusions were responsible for the failure of surface spalling.

**Keywords**—Sendzimir mills; surface spalling; fatigue failure; inclusion; contact stress

## I. INTRODUCTION

SINCE the early 20<sup>th</sup> century, many well-developed industrial countries started to mass-produce a variety of stainless steels. The demand of stainless steels for whole world is often closely related to the global economy will be growing up or not. Concerning the stainless steel products, as-rolled products, for example the cold-rolled sheets, are the most typical ones. Regarding to the production of cold-rolled sheets, not only to ensure the precise thicknesses and excellent surface quality of the sheet, but also to subject the high strain-hardening stress as well as keep the cost competitive. Therefore, the rolling mills play an important role. For the sake of efficiency and economy, Sendzimir mills are one of the most common types, as shown in Fig. 1. The reasons why Sendzimir cold-rolling mills are so favored are characterized with 1. the hardened tool steel rolls can withstand higher rolling stress so the pass of stress-relief annealing can be reduced, 2. the replacement of rolls is ease, 3. the surface quality of rolled sheet is superior. Based on the above characteristics, it is clear to realize that the quality of sheet products and production efficiency strongly depend on the rolls. According to previous reports [1], the materials of work, 1<sup>st</sup> intermediate, 2<sup>nd</sup> intermediate and driven rolls are usually selected with M2 high speed steel, D1~D4 high Cr and high C tool steels, respectively. However, fatigue failure after long-cycled heavy duty of these rolls was happened occasionally, which resulted in the quality of sheet products being unsatisfied even more damaged the whole rolling mills equipment. Therefore, in this study, a failure of 1<sup>st</sup> intermediate roll caused by the surface spalling was analyzed.

## II. EXPERIMENTAL PROCEDURES

One 1<sup>st</sup> intermediate roll of the Sendzimir cold-rolling mills was found to be failure due to some spalling were happened on the surface, as shown in Fig. 2. After be examined carefully by visual inspection,

Shiang-Cheng Jeng is with the Technology and Science Institute of Northern Taiwan, Department of Mechanical Engineering, Taipei, Taiwan, (phone: 886-2-2892-7154; fax: 886-2-2893-5295; e-mail: sccheng@tsint.edu.tw).

Horng-Shing Chiou is with the Technology and Science Institute of Northern Taiwan, Department of Electrical Engineering, Taipei, Taiwan, (phone: 886-2-2892-7154; fax: 886-2-2893-5295; e-mail: hcchiou@tsint.edu.tw).

three sample blocks with surface spalling, cracks and subsurface cracks were taken by wire cutting carefully. Then these spalling and fractured surfaces were examined by stereo microscope and scanning microscope respectively. The micro-hardnesses of the subsurface were also detected by Knoop and Vickers indenters under 500 g load. Furthermore, the microstructure examination and the chemical composition were also performed by optical microscope, scanning electron microscope and glow-discharged spectrometer, respectively.

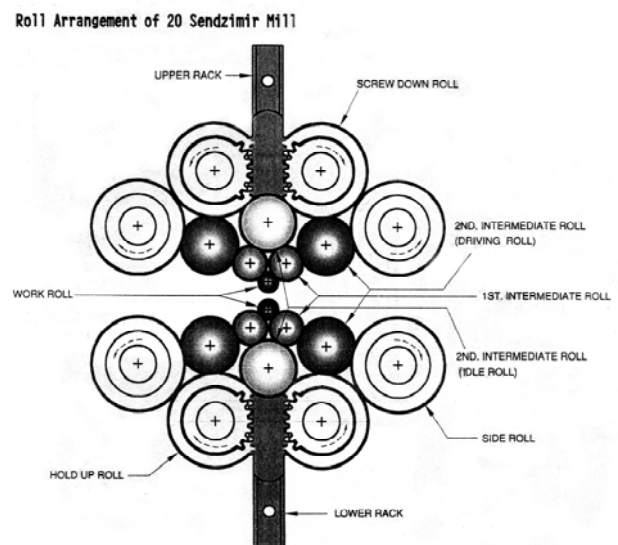


Fig. 1 The schematic rolls arrangement

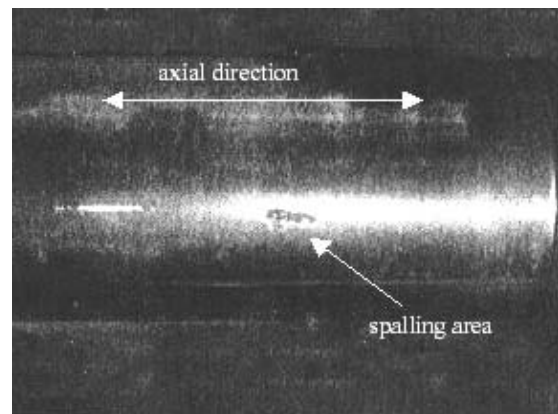


Fig. 2 A macrograph of the surface spalling roll of Sendzimir mills

## III. RESULTS AND DISCUSSION

After visual and stereo-microscope observation, it is found that the spalling areas revealed by elongating along the axial direction of the roll and characterized with an "apex" tips, as indicated in Figs. 2 and 3. Meanwhile, there are some small pits and cracks existing on the surface which are located under the spalling areas, please see Fig. 4.

Based on these above observations, such feature of failure seems to be belong to the type of contact fatigue, which is related to periodically and repeatedly subject high contact stress as well as slide between two contact rolls [2~5]. The factors caused pitting include contact stress, metallurgical microstructure and the chemical or physical characteristics of contact surface, such as lubricant [2~5]. Since there are other rolls in the same mills equipment during operation, but only one roll is damaged. Therefore, it is worthy to investigate in more detail. As a result, there are some deformed voids existing on the fractured surface within the circled area in Fig. 5, in addition, some voids on the fractured subsurface and certain subsurface cracks nearly parallel the contact surface could be observed, as shown in Fig. 6. The failure mechanism of these features was different from previous observation on the contact surface. According to the previous reports [6~9], when the roll was pure rolling without sliding, the maximum Hertz stress will occur slightly below the surface, then initiate a void and cracks propagate. On the contrary, when the roll combined the rolling and sliding, the maximum Hertz stress not only increased but more closed to the contact surface. Both of these conditions will result in surface spalling. In order to clarify what reason predominantly caused the surface spalling happened in this study, some small pieces with cracks were cut carefully, and then broke these pieces into two segments along the original cracks. Then further examination were performed on these new fractured surface, it is clearly to see that the characteristic feature of fatigue failure, "beach marks", is present on the original crack surface, as shown in Fig. 7. In this figure, it is also seen that the crack was originated from a void located at subsurface. In addition, there are some of them having inclusions within the voids, an example is shown in Fig. 8. Based on these features such as spalling shape, location of subsurface cracks, voids as well as an inclusion site, it is inferred that the surface spalling should be resulted from the subsurface cracks. According to Hertz et al. reported [3~6]: when a rigid cylinder contact with rigid plate, the maximum contact stress will occur at the contact surface, otherwise it will occur at subsurface while the cylinder and plate are elastic. Bareis et al. had also proposed that the residual could changed the hardness [10~11]. Petty et al. further verified this proposal by a hardness distribution test on the subsurface of aluminum alloy plate [11~12]. Therefore, a micro-hardness distribution test was performed and the result was shown in Fig. 9. It is obvious that there is a maximum fluctuation of micro-hardness between the 0.02 ~ 0.20 mm regions. This region is coincident with the site of originated fatigue crack that was observed above. In addition, a chemical composition was analyzed by glow-discharged spectrometer and listed in table 1. One can see that the Cr and C contents are about 4.85 and 0.48 wt.%, respectively, which are different from ordinary D-type tool steels. Fig. 10 shows the microstructure of the subsurface region is a tempered martensite. There is no larger carbide could be found within the matrix. In the meantime, the hardness was determined to be HRC 55.4 ~ 57.6. However, based on the recommendation of the Sendzimir cold-rolling mills equipment, the hardness of 1<sup>st</sup> intermediate roll should be ranging from HRC 58 to 62 [1]. Apparently, the hardness of the roll in this study is too low to withstand the high contact stress, so that it should be the predominant factor to originate the subsurface voids and propagate of the subsurface cracks.

#### IV. CONCLUSIONS

1. There are surface pits, cracks and spalling of the 1<sup>st</sup> intermediate roll were observed in this study, which is resulted from the contact fatigue.

2. Surface pits are usually caused by the contact stress, metallurgical microstructure and the chemical or physical characteristics of contact surface, such as lubricant. Here, this is not the predominant effect to induce the surface spalling.
3. In this study, the inclusions and inadequate hardness of the 1<sup>st</sup> intermediate roll, which could not withstand the high contact stress apparently should be responsible for the failure of surface spalling.
4. Material of the 1<sup>st</sup> intermediate roll in this study is different from those recommended in previous reports, D2 tool steel. And the mainly chemical composition of this studied roll is about 0.48 wt.% C and 4.85 wt.% Cr. 1.25 wt.% Mo and 1.04 wt.% W alloy elements steel.

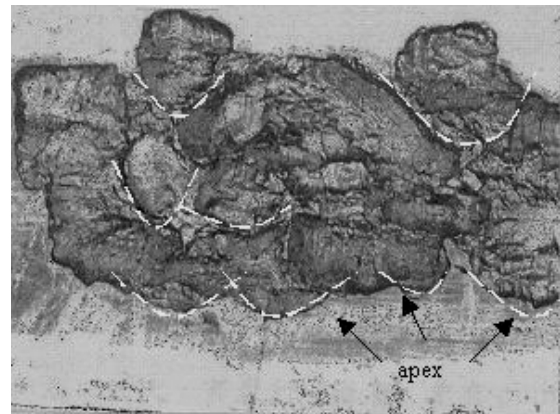


Fig. 3 A stereograph of the spalling area.( 8X )

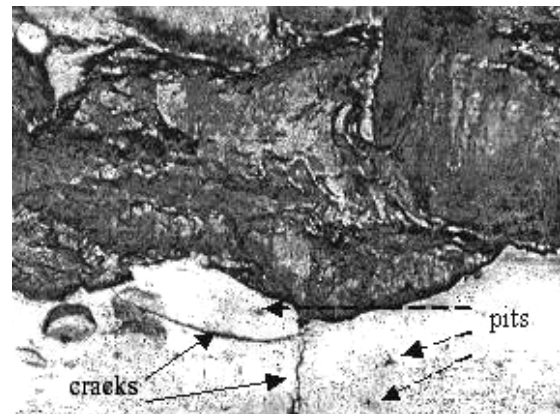


Fig. 4 The lower portion of the spalling area. (32X )

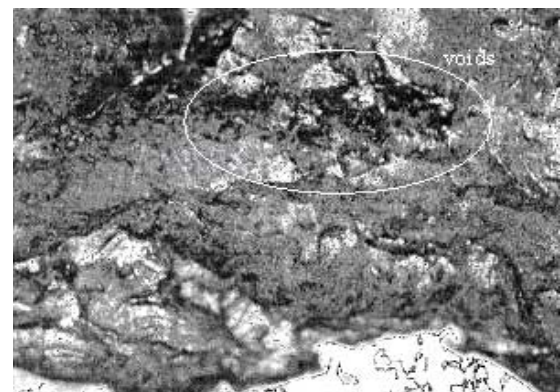


Fig. 5 A higher magnification of the spalling area. (64X )

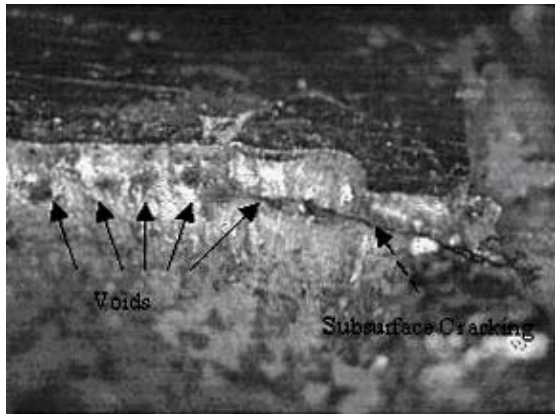


Fig. 6 The side-viewed of the spalling area. (64X )

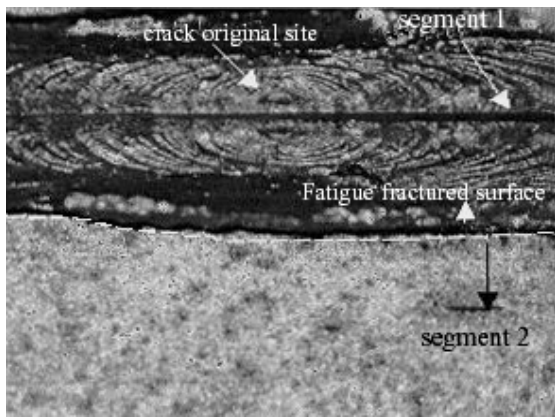


Fig. 7 An example of the fatigue fractured surface. (32X )

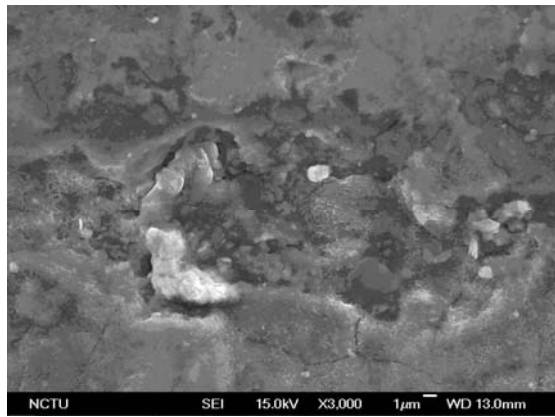


Fig. 8 A SEM micrograph of the origin of fatigue crack

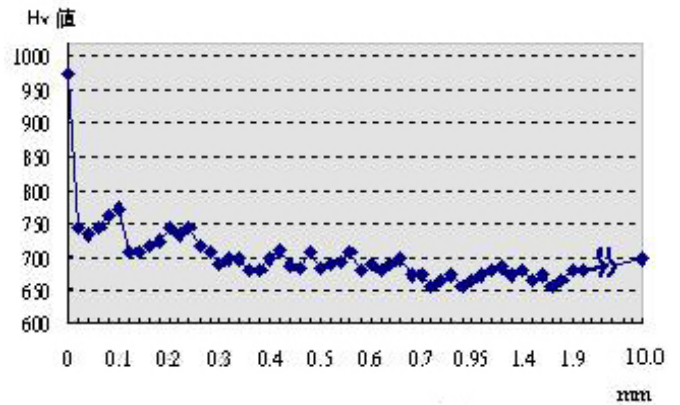


Fig. 9 The micro-hardness distribution of the subsurface

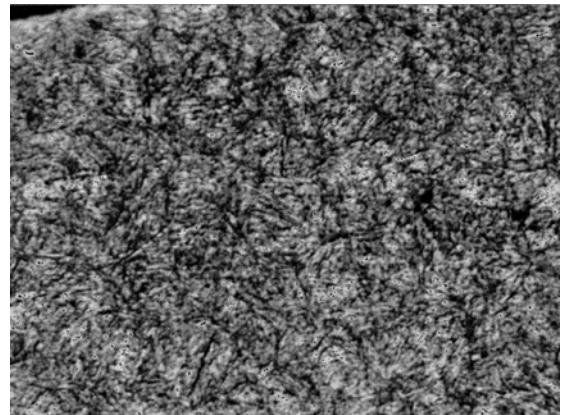


Fig. 10 A optical micrograph of the subsurface microstructure

TABLE I  
 THE CHEMICAL COMPOSITION OF ANALYZED ROLL (WT. %)

element	wt%	element	wt%
C	0.470~0.485	P	0.019~0.020
Si	0.873~0.911	S	0.003
Mn	0.457~0.467	Cu	0.058~0.064
Ni	0.087~0.088	Ti	0.010~0.011
Cr	4.840~4.856	Al	0.011~0.013
Mo	1.242~1.252	V	0.326~0.330
W	1.035~1.045	Fe	bal.

#### ACKNOWLEDGMENT

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