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Premature failure analysis of forged cold back-up roll in a continuous tandem mill

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ABSTRACT

In this paper, premature failure of a forged back-up roll from a continuous tandem mill was investigated. Microstructural evolutions of the spalled specimen and surface of the roll were characterized by optical microscopy, X-ray diffraction, scanning electron microscopy and ferritscopy, while hardness value of the specimen was measured by Vickers hardness testing. The results revealed that the presence of pore and MnS inclusion with spherical and oval morphologies were the main contributing factors responsible for the poor life of the back-up roll. In addition, metal pick up and subsequently strip welding on the surface of the work roll were found as the major causes of failure in work roll which led to spalling occurrence in the back-up roll. Furthermore, relatively high percentage of retained austenite, say 9%, in outer surface of the back-up roll contributed spalling due to conversion of this meta-stable phase to martensite and creation of volume expansion on the outer surface through work hardening during mill campaign.

1. Introduction

In rolling mill operation a four roll high stand tandem mills including two work rolls and two back-up rolls are used to reduce force and power of work roll as well as increase the accuracy and thickness uniformity of thin sheets. Back-up rolls are the main trait of hot and cold roll mills which decrease unintended bending and support the work rolls, enabling them to endure higher loads without failing [1]. Work roll reduces the thickness of strip by plastic deformation which creates by high compressive stress via the rolls. Generally, steel material used for back-up roll is refined in electric arc furnace followed by vacuum degassing. The produced ingot is then forged and subsequently differential heat treatment is performed in order for the material to withstand the campaign in milling. Repeated loading under bending and compressive stresses, severe friction and wear under corrosive environments at high temperatures are some conditions that back-up rolls should endure during mill campaign [2,3].

The main reason for premature failure of the forged back-up roll can be the combined effects of mechanical and metallurgical factors. Mechanical factors include rolling parameter misalignment, uneven roll surface, lubrication, bearing, rolling speed seizure, insufficient stock removal during grinding and the experience of operators [4,5]. Metallurgical factors comprise the presence of non-metallic inclusions, localized overloading, casting defects, temperature gradients due to insufficient cooling and phase transformations [5,6]. It was observed [6] that spalling, cracking, metal pick up and subsequently strip welding are three critical factors responsible for the poor service life of back-up and work rolls during milling operation.

Spalling can be classified into two types. The first type is surface initiated spalling, which is identified by fatigue path accompanied arrest marks, originate from thermally crack or mechanically indentation, and subsequently fatigue path propagates circumferentially opposite to the direction of roll rotation. The second one, sub-surface initiated spalling, which is recognized by the presence of a concentric fatigue pattern (fish eye) on the fracture surface with arrest marks in the form of oval pattern, originates from a material defect and propagates in different directions away from the initiation site usually within a single plane of propagation [3]. In the present study the premature failure of a forged back-up cold roll used for continuous tandem cold strip rolls was investigated. The main factors affecting the premature failure of the forged back-up roll were determined and analyzed [3,7].

2. Experimental procedure

A spalled sample from a forged back-up roll used in a 5 stand 4 Hi tandem mill was investigated. The chemical composition and detailed specifications of the forged back-up and work cold rolls are given in Tables 1 and 2, respectively. The sample was washed thoroughly with running distilled water, rinsed and ultrasonically degreased with acetone and dried. Afterwards, it underwent

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Table 1
Chemical composition of the 3Cr–MO steel (wt.%).

C	Si	Mn	P	S	Cr	Mo	Ni	Sn	As	Cu	Al
0.68	0.31	0.77	0.014	0.008	3.15	0.69	0.07	0.005	0.009	0.045	0.003

Table 2
Detailed specifications of the investigated back-up and work rolls.

Back-up roll size (mm)	4822 × 1525∅
Back-up scrap size (mm)	4822 × 1365∅
Back-up roll weight (kg)	36310
Back-up scrap weight (kg)	31680
Back-up surface hardness (HV)	551–587
Depth of hardened layer (mm)	160
Work roll size (mm)	3765 × 585∅
Work roll scrap size (mm)	3765 × 510∅
Work roll weight (kg)	4865
Work roll scrap weight (kg)	4008
Work roll surface hardness (HV)	874–952
Depth of hardened layer (mm)	75
No. of stands	5
Annual production (ton)	1500,000
Maximum speed (m/min)	1150
Entry strip thickness (mm)	2–4
Exit strip thickness (mm)	0.18–3
Coil width (mm)	650–1500

microstructural and fractographic examinations. To prevent converting back-up roll being scraped and any phase transformation during cutting as well as to obtain reliable results several methods were investigated for sampling; consequently a ring (Fig. 1a) measuring 1365 mm in diameter, 15 mm in thickness and 100 mm in depth was carefully removed during 24 h from a tandem mill back-up roll by heavy duty lathe machine (INNSE 62″). Several samples (Fig. 1b) were then cut from the ring for further microstructural and microhardness experiments.

Microstructure of the samples prepared from the working surface and spalling specimen was characterized via optical and scanning electron microscopes (SEM) equipped with energy dispersive spectrometry (EDS), while microhardness value of the samples was measured by Vickers hardness testing method using 10 kg force. For microstructural examination of phases, the specimens were etched in Vilella's reagent (1 g $C_6H_3N_3O_7$, 5 mL HF, 95 mL CH_3CH_2OH) and Beraha's reagent (3 g $K_2S_2O_5$, 10 g $Na_2S_2O_3$, 100 mL H_2O). Fischer MP3 ferritscope was employed to measure the amount of ferromagnetic α′-martensite phase of the samples. X-ray diffraction (XRD) analysis was carried out on the samples to measure retained austenite content by measuring the integrated intensities of (1 1 1)γ and (1 1 0)α′ diffractions using the following equations [8]:

$$V_\gamma = 1.4l_\gamma/(I_{\alpha'} + 1.4l_\gamma) \quad (1)$$

where V_γ is the volume fractions of austenite and I_γ and $I_{\alpha'}$ are the integrated intensities of (1 1 1)γ and (1 1 0)α′ peaks, respectively.

3. Results and discussion

3.1. Hardness profile measurement

Hardness profile, Fig. 2, was measured at every 5 mm distance from the working surface of back-up roll. As can be observed, hardness value of the samples decreased from 607 to 489 HV with increasing the distance from the working surface. However, there was a fluctuation in hardness value between 607 and 553 HV until the 17 mm distance from the surface of the back-up roll. The result revealed that the hardness value of the roll was almost close to the normal, whilst the main reason of fluctuated behavior in hardness profile may attributed to the softening some parts of working surface [3,4]. Fig. 3 shows the microstructure of the softening regions indicating a large amount of precipitated carbide caused by superficial tempering due to localized heating.

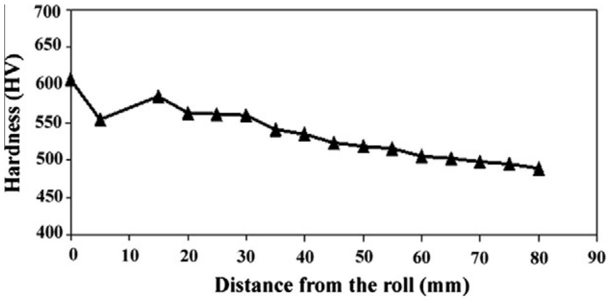

Fig. 2. Hardness profile of back-up roll.

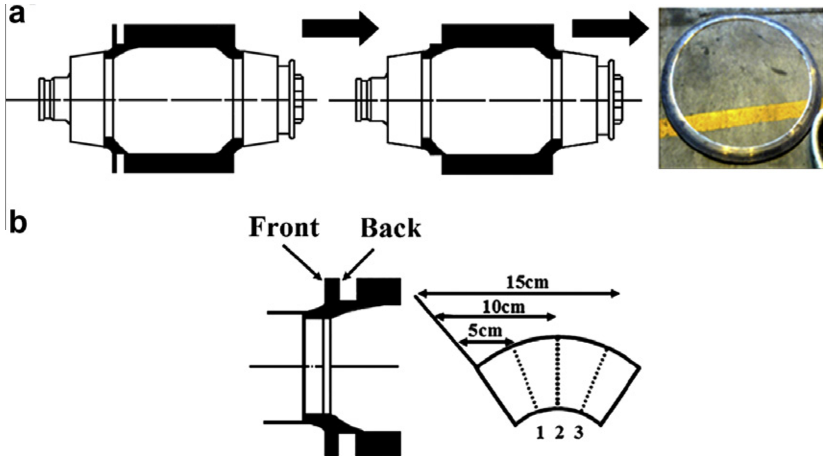

Fig. 1. (a) The ring cut from the tandem mill back-up cold roll and (b) samples cut from the sector of the ring.