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Failure analysis of ICDP work roll of hot strip mill case study of shell-core interface spalling

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Abstract—The failure of the roll during the rolling process causes cobble to lose production time for several hours. Investigations include visual inspection, lltrasonic test, chemical analysis, metallography, and hardness measurement. Stand finishing F1-F4 uses High Chrome (HCr) material type, while Stand F5-F6 uses ICDP material type. Spalling work roll occurs on stand F5 with Roll Top position. Roll was chipped between shell and core with an exfoliation percentage of 30% of the roll surface area. Visually, the chipped part looks smooth and even. Thus, no typical sign of fatigue or brittle failure was observed. The chemical composition of the roll conforms to the standard. Roll surface hardness that does not experience spalling follows the standard. The metallography analysis found micro-cracks in the spalled samples and inclusions in the form of scale in the shell-core interface. Based on the study, it can be concluded that the spalling roll is caused by poor bonding of the shell and core on the roll.

Keyword: *ICDP Work Roll, Hot Strip Mill, Shell-Core Interface, Spalling*

I. INTRODUCTION

Hot Rolling Steel is a metalworking process carried out at high temperatures, namely at the steel's recrystallization temperature. Generally, several facilities are in the hot rolling process, as illustrated in the figure 1.

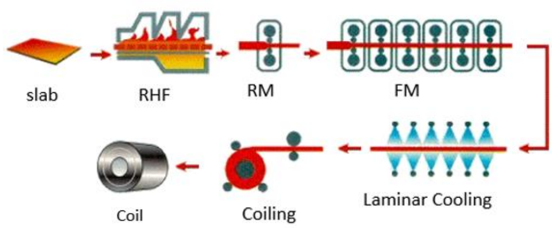


Figure 1. Hot strip mill process flow

The finishing stand consists of two types of work rolls. Stand F1-4 used High Chrome roll material, while the Finishing stand F5-F6 used ICDP roll material. A successful rolling operation must be supported by good properties such as (a) good wear resistance, (b) fire cracking resistance, (c) oxidation resistance, and (d) excellent surface finish grinding results (Palit et al., 2015). The rolling speed is higher on the F5 and F6 stands, so it requires good wear resistance. ICDP roll was used in the last stand because it has good wear resistance and thermal fatigue properties (Sinha et al., 2014). The roll consists of a hard shell and core. The shell is made of alloyed cast iron, while the core is made of gray/nodular cast iron. The premature failure of the roll is generally caused by: surface degeneration, fire crack, surface indentation, and spalling (Sinha et al., 2014). Surface degeneration failure, fire cracks, and surface indentation, although progressive, can be overcome by roll grinding operation. Rolls can be reused after grinding with reduced roll diameter. The roll cannot be reused if the roll diameter has reached the diameter of the scrap. The grinding roll process was generally carried out by Eddy Current test (ECT) or Ultrasonic Test (UT) on the grinding machine to ensure good roll quality.

On the other hand, the spalling roll was a problem that can result in mill stoppage and thus the loss of production time; also, the roll cannot be reused if the spalling reaches the scrap diameter. The new roll must be inspected with the NDT ultrasonic test (UT) to ensure that the roll quality is good. Generally, a roll has a history of use in the form of a roll card until the roll becomes scrap. The roll card will monitor the quality and diameter of the roll.

In this paper, the authors investigate the premature failure of the ICDP Roll used in the final stand i.e., stand F5 of a hot strip mill. The roll used has an initial diameter of 650 mm and a scrap roll diameter of 585mm. Spalling work roll occurs on stand F5 with Roll top position. After the spalled occurs, the roll becomes scrap because the shell was separated from the core with an area of 30% of the total area of the barrel roll. Set roll was used for rolling with thickness variations 2.25 – 6.5 mm and slab width variations 945 – 1250. The failure can be described as peeling off part of the shell from the core on the ICDP roll causing cobble in the hot rolling process at the mill.

II.METHODS

Figure 2 shows a general view of the spalled roll. Rolls that have been spalled are subjected to a visual test to identify failure modes. Chemical composition was measured by spectrometer. A specimen from the roll spall was cut for metallography analysis, as shown in Figure 3. The specimens were mounted with resin and then ground using a grinding machine and polished to 3 microns using standard metallographic techniques. The polished specimens were etched with 2% Nital solution to reveal the microstructures.

Roll spalled hardness test carried out with a micro hardness test (Fig 4). The microstructure of spalled parts of the cross-section was investigated by scanning electron microscopy (SEM) with EDS, and micro-hardness with 50 gf. The depth and position of the spalling were measured by UT Test and manually using a scale.

Figure 2. General view of the spalled roll

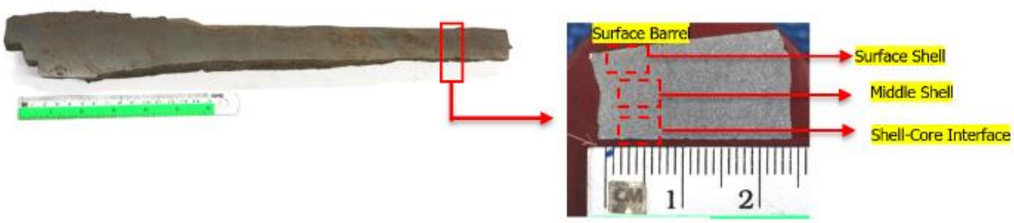


Figure 3. Specimen for cut analysis

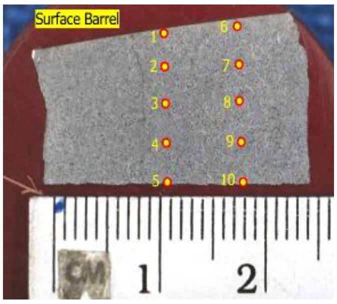
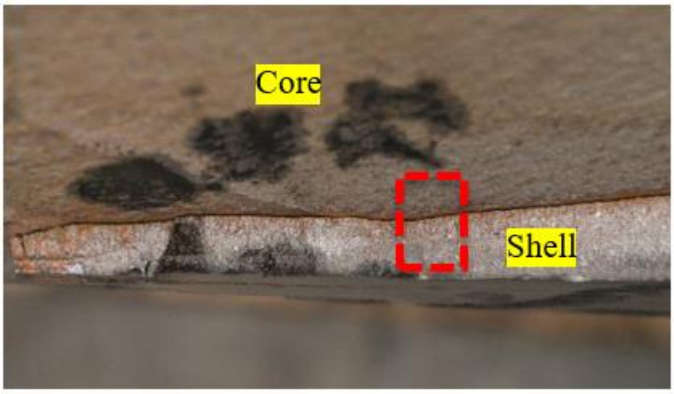


Figure.4. Location of microhardness testing on the spalled sample (shell)



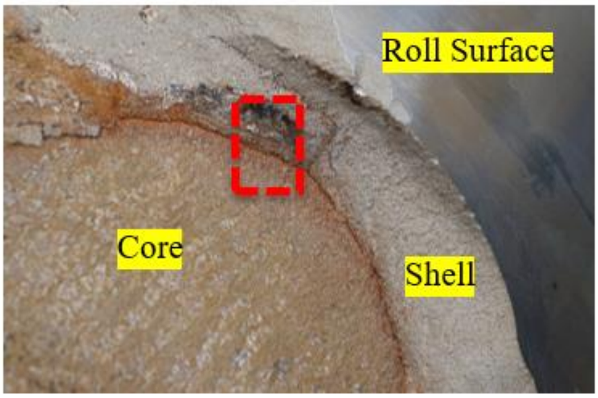


Figure 5. Detail of spalled roll (shell and core)

Table 1. Chemical composition (wt.%) of the spalled sample

C	Si	Mn	P	S	Cu	Ni	Cr	V	Al	N	Mo	Ti	Ca
3.074	1.049	0.948	0.0484	0.0330	0.023	3.975	2.042	0.105	0.003	0.0065	0.442	0.0259	0.0020

III. RESULTS

From the visual observation in Figure 5, it shows that there was a gap between the shell and the core (the part marked in red). This indicates that the shell and the core bond are not good. The bond between the shell and the core is not good, making it easy for this type of spalling to occur. Chemical analysis of the samples was carried out using an Optical Emission Spectrometer (OES) (Model: ARL 4460). The results of the chemical analysis obtained are in Table 1. The samples were tested for hardness using a micro hardness vicker. The results of the hardness test are shown in the Table 2.

Table 2. Result of micro hardness analysis on location marked in Figure 4

No.	Hardness Value (HV)	No.	Hardness Value (HV)
1	764	6	655
2	660	7	651
3	716	8	804
4	721	9	730
5	776	10	782

The average hardness value of the shell roll is 725.9 HV.

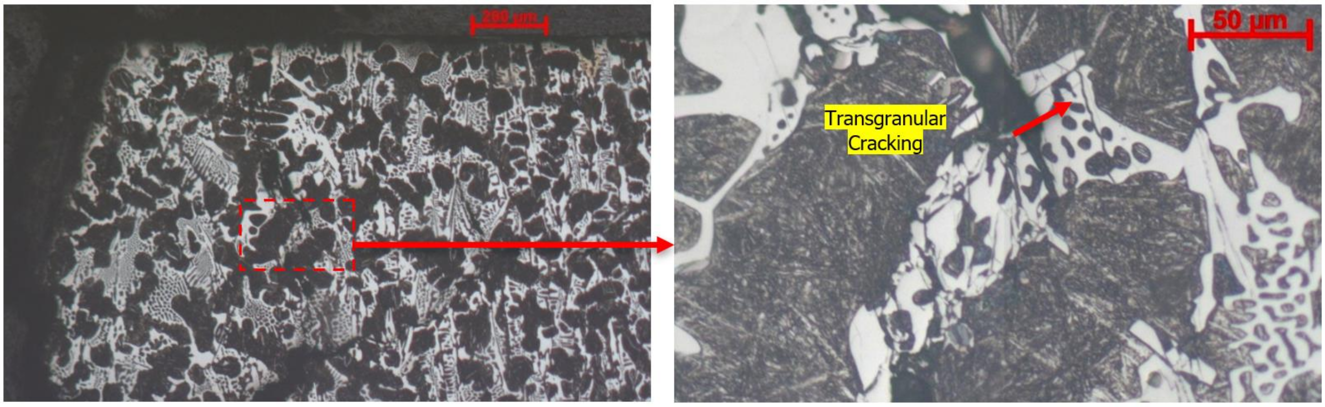


Figure 6. The microstructure of the spalled sample

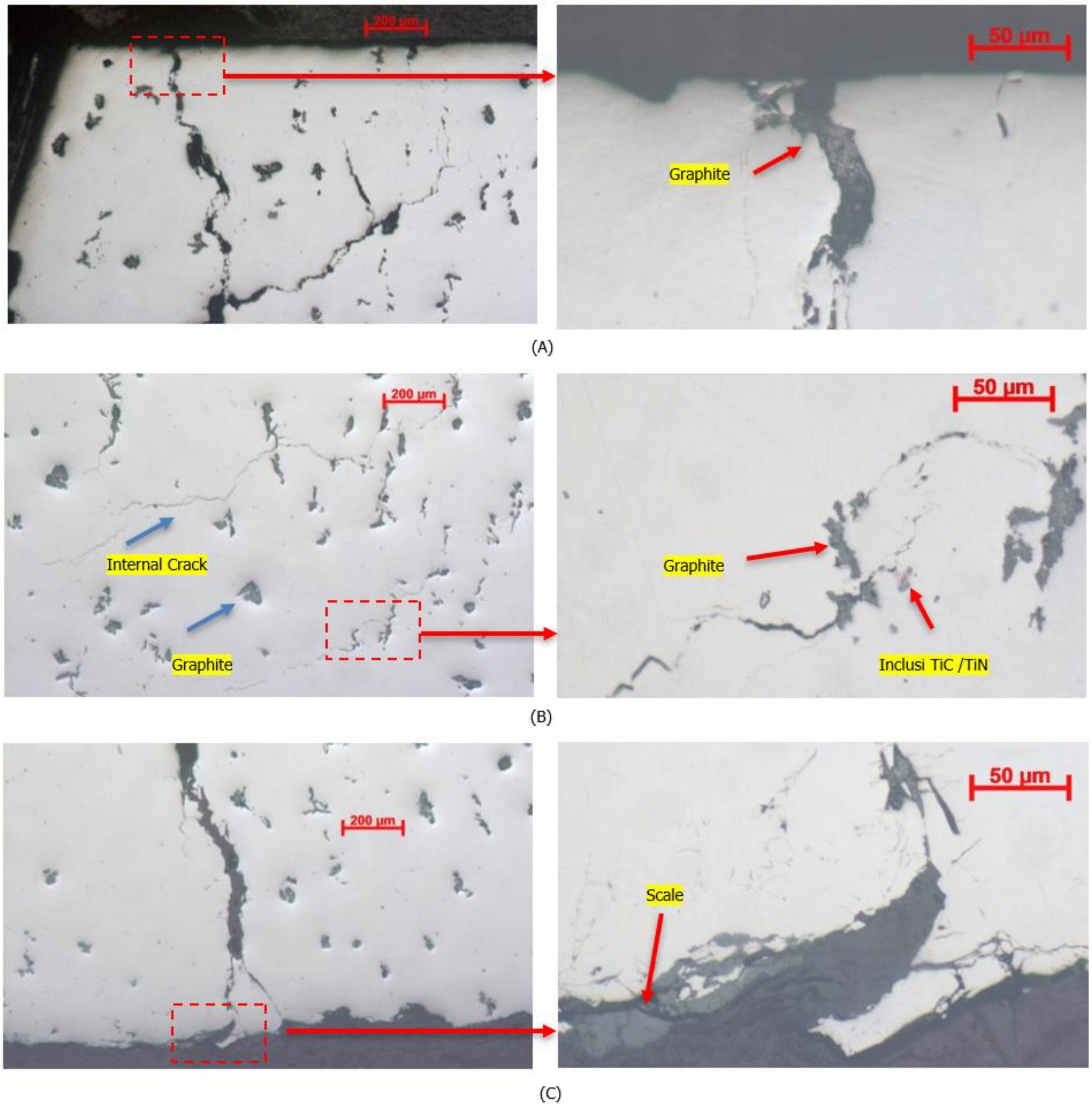


Figure 7. The microstructure of the cross-section of the shell . (A) at the surface shell, (B) at the middle of shell and (C) at the shell-core interface

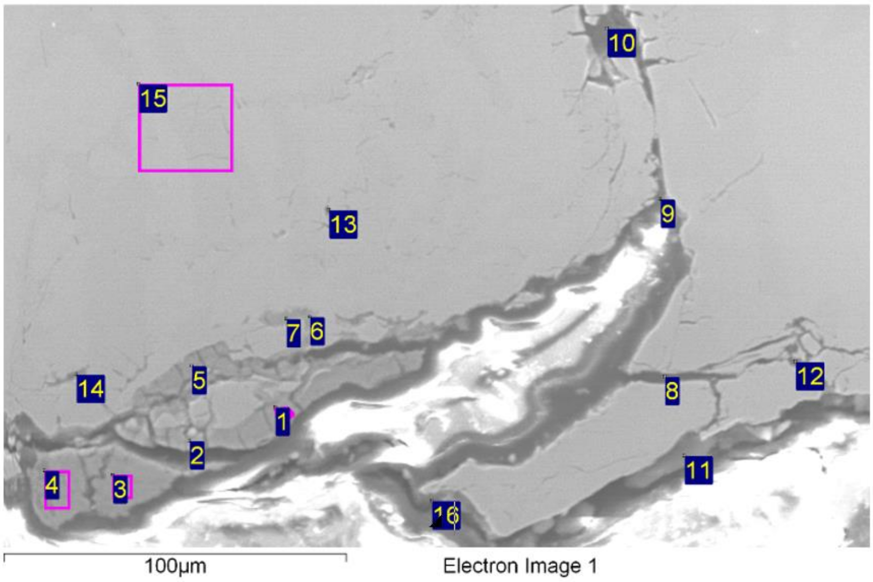


Figure 8. EDS analysis of spalled sample on the shell – core interface

Table 3. Result of EDS analysis

Spectrum	Weight (%)										
	C	O	Al	Si	S	Ti	Cr	Mn	Fe	Ni	Total
1	14.11	33.82	-	0.31	-	-	-	-	49.80	1.96	100.00
2	11.65	35.81	-	0.74	-	-	-	-	49.55	2.25	100.00
3	14.53	33.83	-	0.46	-	-	-	-	48.96	2.22	100.00
4	20.80	33.63	-	0.40	-	-	-	-	43.48	1.69	100.00
5	16.26	35.84	-	3.66	-	-	1.71	-	38.37	4.15	100.00
6	7.29	32.99	-	2.17	-	-	1.00	0.95	51.93	3.67	100.00
7	13.51	29.03	-	2.34	-	-	1.65	0.86	49.28	3.34	100.00
8	63.78	15.42	-	-	-	-	-	-	19.97	0.83	100.00
9	56.42	22.55	-	0.22	0.27	-	0.73	-	19.15	0.66	100.00
10	93.91	3.60	-	-		-	-	-	2.50	-	100.00
11	64.57	21.59	1.07	0.86	0.52	-	-	-	11.39	-	100.00
12	44.67	12.30	-	-	-	-	1.42	-	41.60	-	100.00
13	27.15	6.32	-	-	-	0.78	2.08	-	61.98	1.69	100.00
14	12.73	-	-	-	-	-	4.24	1.78	81.25	-	100.00
15	10.44	-	-	-	-	-	2.78	1.55	82.72	2.51	100.00
16	37.34	14.42	0.73	-	-	-	0.96	-	45.60	0.96	100.00

Metallography was carried out to examine the microstructure of the roll at the location of spall. Microstructure obtained by SEM with EDS is shown in Fig. 6 and fig 7. The microstructure is a matrix of martensite with graphite. In the shell, inclusion TiC and TiN and micro cracks were found with the type of transgranular cracking. The results of the EDS test in the Shell-Core interface area were found to be oxide or scale compounds. The results of the EDS test can be seen in table 3 Crack propagation mapping has been measured using an ultrasonic test with the USKS 8S type. UT test parameters are presented in the table 4. The propagation of the crack can be seen in Figure 9. The propagation of the crack is 7-45 mm deep around the non-spalled area on the Operating Side.

Table 4. UT Inspection Parameters

Inspection Parameter	**Detail**
Detector Model	USKS 8S
Probe Type	MSEB-4H
Callibration Block	V1
Couplant Used	Oil
∅ registration	1.5 mm pada V1
dB operation	100 % FSH +6db
Range	100 mm

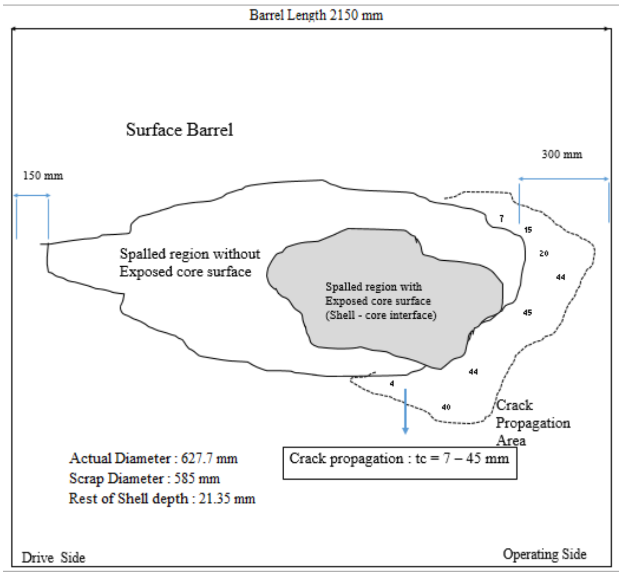


Figure 9. Two-dimensional projection of ultrasonic test results on a spalled roll

IV. DISCUSSION

Roll failure in the hot rolling mill process is a common problem. Spall on work roll finishing can occur in stands F1- F6. In this case, the work roll spall occurs at the finishing stand F5. This problem causes production delays for several hours. The new roll diameter is 650 mm, while the scrap diameter is 540 mm. The roll diameter at the time of failure was 627.7 mm. From the visual observation of the roll, the spall occurs from the surface to the roll core. The spall depth is about 22 mm, which is the thickness of the shell before being scraped. Furthermore, it shows that there was a gap between the shell and the core. It means shell-core unbinding when a failure occurs. The results of the chemical composition test show that the roll is typical of the ICDP roll. The hardness results show an average value of 725.9 HV.

The microstructure of the shell samples tested showed a martensitic matrix with the presence of graphite. This microstructure is typical in ICDP rolls. Intergranular cracking in the shell is around the graphite phase. Intergranular cracking initiates crack propagation when a roll spall occurs. Fig 7 shows that the presence of graphite in the ICDP causes deformation and cracking in connection to graphite-rich regions under loading. Graphite phase is beneficial since it may act as a solid lubricant reducing the interfacial friction force in the sliding contact (Nilsson & Olsson, 2013). EDS analysis confirmed the oxide or scale at the shell-core interface.

Ultrasonic evaluation of the spalled roll revealed a crack propagation from the exposed spalled region at the operating side. The depth of the crack was 7-45 mm. The propagation crack may be a consequence of spalling. Cleanliness from ICDP's casting roll will significantly affect the bonding of shell and core. Some of the causes that make the shell and core bond wrong are the residual oxide layer between the shell and the core, flux or slag at the interface, excess carbide, microporosity, graphite flakes, or non-metallic inclusions such as sulfides (Roll Failures Manual Hot Mill Cast Work Rolls, 2002)[. Scale or oxide on the shell core interface, causing the bond between the shell and the core to be weak.

Combining all the observations, it can be inferred that the roll spalled because of the influence of the quality of the roll. Where the weak bond between the shell and core causes spalling on the roll so that failures in the mill due to spalled rolls are not repeated, make sure the roll quality from the manufacturer is good, mainly from the strength of bonding between the shell and the core. Make sure that before the new roll is used, the NDT ultrasonic test is carried out to see if there are abnormalities in the roll. used, the NDT.

V. CONCLUSION

From the results of the analysis above, it can be concluded that the roll spall occurs because of the weak bond between the shell and the core. Lack of bonding between shell and core due to scale or oxides present at the interface.

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