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Failure analysis of rolls of cold rolling mill in steel plant

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ABSTRACT

Failures of rolls occur due to improper manufacturing and operational parameters. The samples of prematurely failed roll samples collected from steel plant were examined for their chemistry, inclusion content, microstructures, carbide characteristics, hardness and the retained austenite content. The residual stresses were also measured on the inner as well as the outer surface of the spalled roll pieces. The results obtained have been discussed in this paper. The higher content of retained austenite was primarily responsible for the spalling of indigenous rolls for which sub zero treatment has been recommended. Several suggestions have also been made for smooth operation of the mill and consequently for the extension of life of a work roll.

INTRODUCTION

The work rolls used in the cold rolling mills are expected to perform under very arduous operating conditions. With the advent of faster mills and the increase in load, the quality of roll needs continuous improvement. Cold mill rolls should withstand mechanical and thermal shock, must have excellent wear resistance and very little plastic deformation.

The premature failure of a cold mill roll increases not only the cost of a roll but also down time of mill affecting the productivity of mill. The reasons of the premature failure can be attributed to the combined effects of mechanical as well as metallurgical factors. While the mechanical factors have concentrated on the misalignment, uneven roll surface and bearing seizure, metallurgists have considered the failure as arising out of localised overloading, temperature gradient, the presence of non-metallic inclusions and phase transformation [1].

The objective of the present work was to analyze the reasons of failure from manufacturing as well as operational point of view and to provide suitable recommendations for extending the life of a cold rolling tandem mill work roll of an Indian Steel Plant..

BACKGROUND

It was observed that the three contributing factors responsible for poor life of a work roll were following :

a) Spalling
b) Cracking
c) Metal pick up & wrapping

Failures of type 'a' and 'b' are partly manufacturing and partly operational whereas 'C' is mostly operational. Amongst these failures, spalling in considered to be the major cause of roll failure in cold rolling mill. A work roll in service is subjected to set of stresses. First of all these are the internal stresses resulting from the heat treatment. On top of these internal stresses are those caused by rolling operation. Spalling is mainly classified into two types [3].

a) Spalling due to fatigue fracture of which origin starts from roll barrel surface or just below the surface
b) Spalling due to fatigue fracture of which origin starts inside the roll body.

Failure of type (a) is related to problems of operational origin whereas type (b) is mostly of manufacturing origin. Factors [4] responsible for the spalling are given below.

Operational factors :

1. Overloading
2. Insufficient stock removal
3. Thermal stresses due to insufficient roll cooling
4. Severe bruising of rolls
5. Mill chatter, improper crowning and mechanical alignment problems
6. Sharp temperature gradient on the surface of the rolls (e.g.) near strip edge.
7. Pickling quality of hot rolled coil
8. Wrong grinding Operation
9. Hydrogen pickup from soluble oil used as a roll coolant

Manufacturer's factors :

1. Non metallic Inclusion
2. Casting and pouring defects such as coarse grained structure or clustered carbides.

3. Heat treatment faults such as poor carbide morphology, coarse martensite, retained austenite and residual stress.

Cracks develop in regions between top hardened surface and subsurface, a few microns below during final grinding stage [5,6]. Due to thermal gradient crack propagates and failure occurs. Crack is also initiated due to compressive stresses experienced during contacts between roll and strip while rolling. They grow under fatigue condition and failure in not usually premature [7]. It is also believed that the inclusions are centres from where the cracks start building up and propagate resulting in spall [3].

Failure also occurs due to metal pick up and wrap-up of coil with roll. Due to breakage of strip, the material gets wrapped up and the temperature increases much above the specified temperature leading to failure.

METHODOLOGY

The detail specification of roll investigated in the present work has been given in Table 1. These rolls are induction hardened forged steel quality and are used in stand 2 to 5 of five stand 4 Hi tandem mill. The data on the lives obtained from the roll manufactured by various suppliers,indigenous as well as imported along with the cause of premature failures were collected. These data are shown in table 2

Samples of prematurely failed rolls from indigenous as well as imported make were collected for examination at NML. The methodology adopted focusses on metallographic features. The etching reagent (4% picral + CH_3OH) was used to see the retained austenite. Inclusion analysis was done to compare indigenous rolls with imported rolls. Residual stress was measured using a x-ray stress analyser AST-2001. Besides this, mill operation was carefully observed in order to suggest the ways and means to extend the life of a work roll.

RESULTS

Fig. 1 shows the damaged portion of an imported as well as indigenous work roll. Typical fatigue lines as well as origin of the crack close to the surface are revealed. These were examined for the following.

I. Microstructure

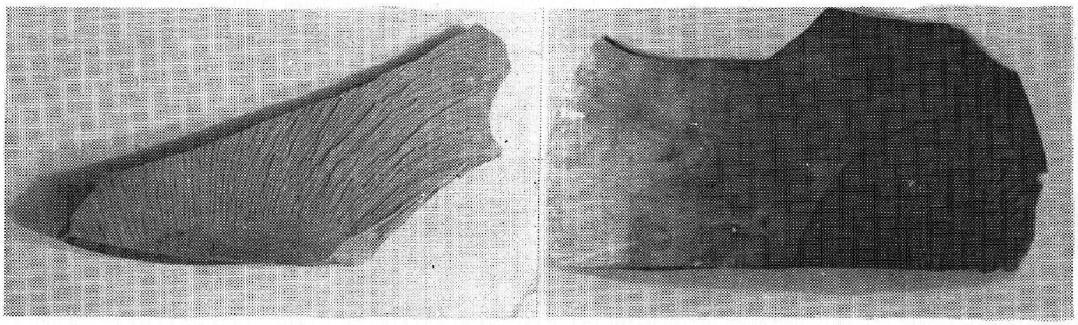
The microstructure (Fig. 2a) of the indigenous roll shows the presence of martensite needles, which was perhaps not converted fully to tempered martensite during heat treatment whereas the microstructure (Fig. 2b) of imported rolls reveal tempered martensite.

Table 1 : Detailed specification of investigated roll

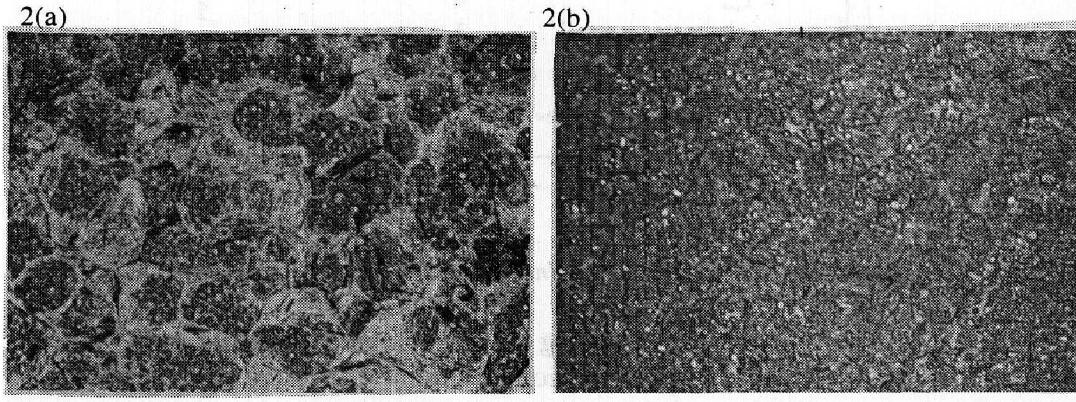
Roll Size	:	585 x 1420 mm B. L.
Scrap Size	:	555 x 1420 mm B.L.
Surface Hardness	:	95-97 Sh D (Amr)
Depth of Hardened layer	:	15-20 mm
No. of stands	:	5
Types of stands	:	All 4 H
Average no of dressings on a roll before scrapped	:	45-46
Bearings	:	Morogoil Bearings on Back up rolls
	:	Taper Bearings on the work rolls.
Drive	:	All rolls are driven by 7500 HP DC Motors
Cooling water	:	Quantity & Pressure 1800l/mm, 6-12 kg/cm^2 with a pH of 7-8
Lubricant with cooling water	:	Palm Oil System A - 8 to 12% System B - 15 to 20%
Maxm. Speed	:	1830 m /min
Pickling Practice	:	Sulphuric acid with inhibitors at a line of 80-120 m/min.
Roll Material	:	Forged Steel (Induction hardened) A typical composition is as follows : C=0.85, Mn=0.35, Si =0.50, Cr = 2-3.5, M = 0.30

Table 2 : Performance data fro the year 1993

INDIGENOUS ROLL			IMPORTED ROLL		
Date of Scrapping	Life obtained	Reason of scrapping	Date of scrapping	Life obtained	Reson of scrapping
15.2.93	20,116	Small spall	2.2.93	51.088	Depression
21.2.93	4,536	spalled at middle	9.2.93	56,167	-do-
4.3.93	3,822	-do-	16.2.93	59,415	Metal pick up
28.6.93	9,419	-do-	9.3.93	39,457	Dep.
6.7.93	25,484	Small spall	29.3.93	52,226	Pickup &spall
12.7.93	5,593	Spalled at middle	5.4.93	40,359	Low hardness
23.7.93	2,684	Spalled at middle	22.4.93	13,031	Pickup & depression
19.9.93	3,162	Spalled at	31.7.93	32,371	Low hardness
21.9.93	9,990	-do-	23.8.93	9,118	Small spall
22.9.93	2,367	Spalled at drive end	31.8.93	8,438	Spalled at one end
9.10.93	6,374	Spalled at at one end	23.9.93	24,218	-do-
24.10.93	10,557	Small spall	10.11.93	42,465	Pickup
4.11.93	22,816	-do-	10.12.93	23,770	Dep.
5.11.93	14,601	Spalled at one end	21.12.93	49,737	-do-



Thermally spalled indigenous roll *Fig. 1* *Thermally spalled imported roll*



x 1000 *Fig. 2* *x1000*

Presence of macteneritic needles and higher percentage of retained austenite in indigenous roll

Presence of tempered martensite and lower % retained austenite in imported roll

II. Retained Austenite

Retained austenite was attempted on X-Ray diffractometer and the patterns obtained (Fig. 3) were carefully examined. The values obtained on the outer surface of different samples of indigenous rolls varied from 6-15% by volume whereas for the imported rolls it was 10.94%.

% retained austenite was also measured on the inner surface by XRD technique using a computer software, at IGCAR Kalpakkam in RIGAKU diffractometer. It varied between 13-15% for indigenous rolls whereas it was about 10.5% for imported rolls.

Retained austenite being a metastable phase, appears to be the main reason

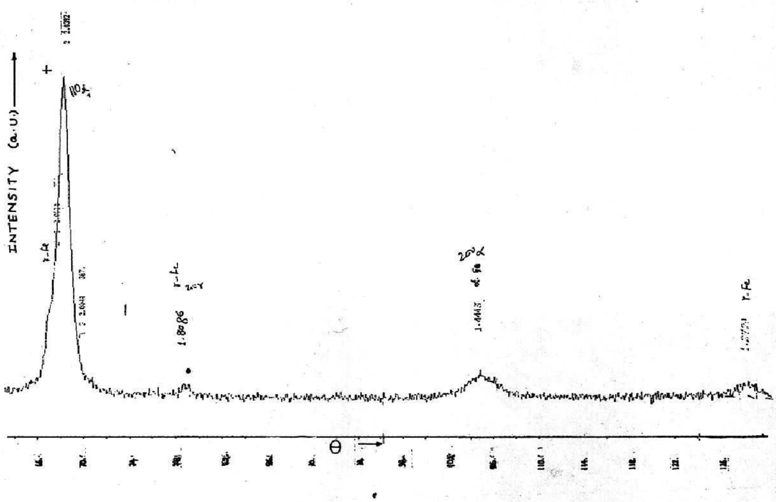


Fig. 3 : XRD pattern of an Indigenous roll (outer surface)

for spalling of indigenous rolls. During rolling retained austenite may be converted to martensite resulting in expansion of volume which create external pressure and cause spalling.

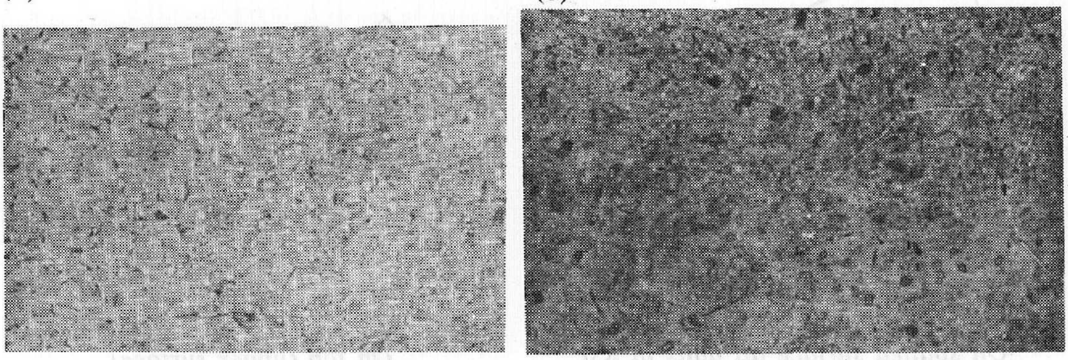
III. Carbides

Carbides were not found to be evenly distributed and globular in shape in indeigenous rolls compared to imported rolls (Fig. 4). This may be due to inadequate soaking during the heat treatment operation, where all the carbides may not dissolve in austenite and the precipitation during quenching may not result in proper distribution and shape and size.

IV. Non-Metallic Inclusions

The steel from imported roll was found to be cleaner than that of indigenous roll. The inclusion content in the imported roll varied in the range of 0.02 to 0.15% by volume. Whereas, in the case of indigenous rolls it was 0.16 to 0.24%. It is believed that the inclusions are the centres from where the cracks start building up. Fig. 5 shows the presence of inclusion on the spalled surface of the rolls & multiple surface cracks initiating & emanating from an inclusion on the surface of imported roll (Fig. 5).

(a) (b)

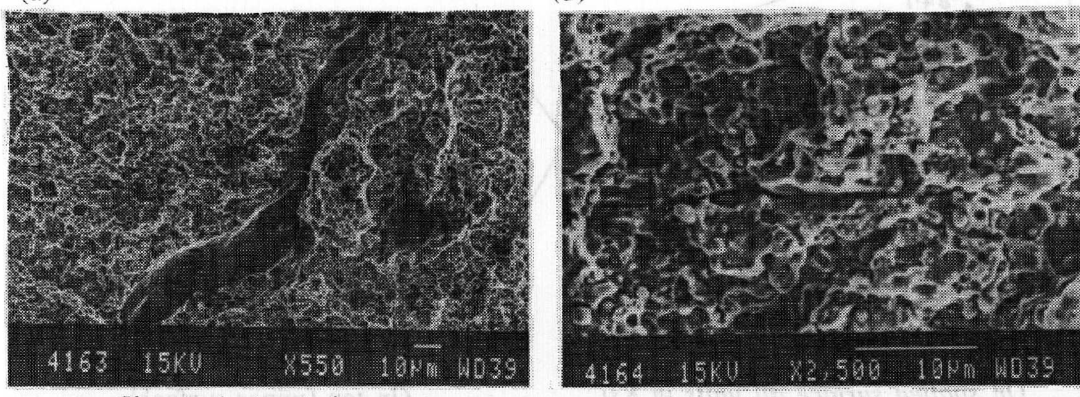


x 800
Indigeneous roll

Fig. 4

x 800
Carbides evenly disttributed in imported roll carbides are glolular in shape

(a) (b)



Slag inclusion indigenous on surface of roll

Fig. 5

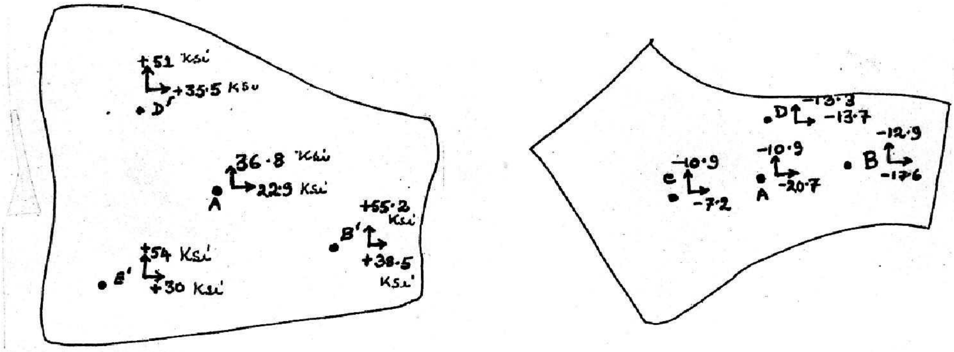
Multiple cracks from an inclusion in imported roll

V. Residual Stress

Residual stresses were measured on the spalled piece along two directions, (a) radial & (b) transverse direction. Fig. 6 shows that residual stresses were tensile on the spalled (inner) surface for the indigenous roll. Whereas for the imported roll, compressive residual stresses were observed on both the surfaces (inner & outer) which are not considered determinantal. However, in-situ measurement of residual stresses during rolling was most important because stresses might have got relieved after spalling.

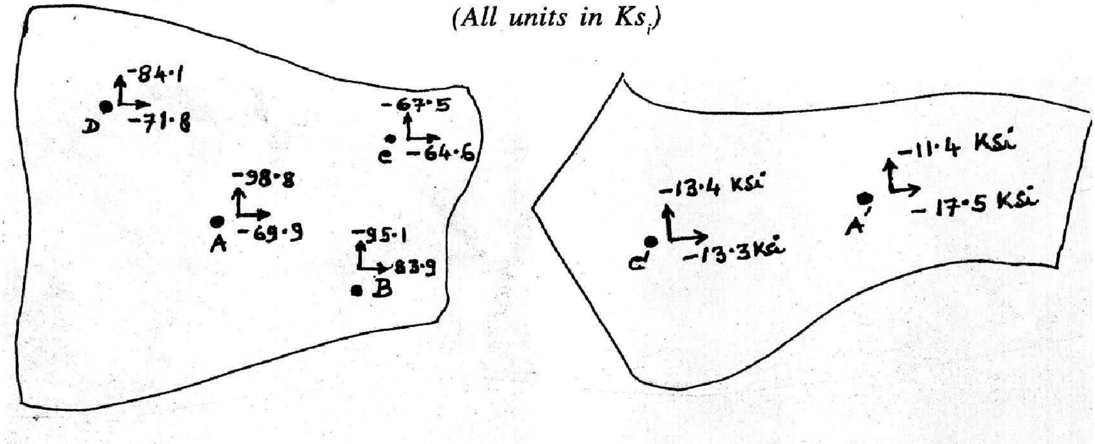
OBSERVATIONS & DISCUSSION

1. The major cause of failure of indigenous roll was due to spalling. The content of retained austenite is more in indigenous rolls compared to imported rolls.



On spalled surface all units in Ksi *On top (upper surface)*

Fig. 6a : Residual stress measurement on failed sample (due to spalling) for indigenous roll (All units in Ks_i)



On spalled surface all units in Ksi *On top (upper surface)*

Fig. 6b : Residual stress measurement on failed sample (due to spalling) for an imported roll (All units in Ks_i)

During rolling retained austenite might be converted to martensite resulting in volume expansion. Thus creating internal pressure to cause spalling. Recommendation was made to go for sub-zero annealing. If it is installed at manufacturer's premises, there is further liberty for trying better compositions and higher alloying with chromium and other elements resulting in better performance.

2. Spalling is also originated from subsurface fatigue crack. The excessive stress concentration takes place on the roll surface at the portion where sharp strip edge contacts the roll. This stress concentration may cause generation of fatigue crack and result in spalling of roll. Therefore, it is advisable to mea-

sure the residual stress at different stages of operation.

3. Because of the severe hardening process during manufacturing, high residual stress is retained in the roll which may affect the performance of a roll. The residual stress of freshly manufactured roll should have been measured in order to suggest the modalities for extending the life of CRM roll.

4. Another cause of roll failure is due to mill abuse, number of mill wrecks or accidents occuring during operation. These accidents are caused by strip breakages and the stock material gets wrapped up around the roll.

   There may also be local metal pick up by the rolls which gets welded with the sheet where the temperature increases much above the specified temperature. Roll fails due to thermal stress. This can be avoided by maintaining proper pressure of the cooling water and its quantity.

   Therefore, smooth mill operation is necessary for the extension of the life of CRM rolls.

5. The performance of the roll also depends on quality of rolling stock and its surface condition. There may be variation in hardness, gauge thickness, surface condition. If strip is under pickled, oxide layer will be present which becomes the source of roll failure.

6. The surface of the roll sometimes get bruised and develops cracks and elimination of these cracks result in scrapping of the roll because diameter goes down.

7. Route of the roll was studied carefully from the roll card. The expected tonnage on stand no. 2 is 500 tons per campaign and 2000 tons per campaign on stand No. 5. If the proper inventory is maintained and the inspection of roll surface is made frequently, it would be possible to increase the life of roll to an optimum tonnage of 40,000-50,000 tons.

CONCLUSIONS

1. It was found that the retained austenite content is more in indigenous rolls compared to imported rolls. This was responsible for the failure of rolls due to spalling. Austenite being the metastable phase in the steel deserved to be converted to stable phases by subzero annealing. It was recommended to instal this facility at manufacturer's.

2. The quality of input (hot rolled strip) is not uniform with regards to its metallurgical characteristics. This needs attention for improving the performance of a roll.

3. Recommendations have also been made for smooth operation of mill. These recommendations have already increased the awareness amongst the rolling

crew during the tenure of the project and there is substantial reduction in failure of rolls and down time in the mill.

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