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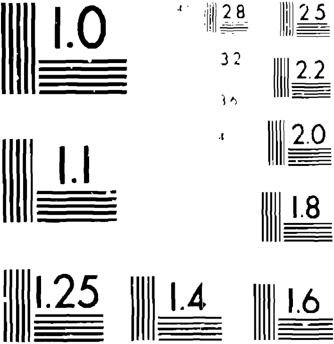

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RECLAMATION OF A SET OF COGGING MILL ROLLS BY WELDING*

by

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INTRODUCTION

Matched segments from both the top and bottom collars between the 205 mm and 190 mm passes of a new set of rolls cracked during service.

The normal repair method of roll turning to below the crack lines would have reduced the lives of the rolls by 62% or, in terms of production, 500 000 tonnes throughput.

Because of the delay in replacing the damaged rolls and to ensure the availability of a spare set of rolls it was decided to repair weld the damaged collars. While this repair procedure is common practice in Europe, it was the first time a reclamation project of this magnitude has been attempted at ZISCO.

Each roll took eight days to repair which involved 136 hours of heat treatment and 76 hours of continuous welding.

Considerations

In view of the high replacement costs and the very serious implications of having to shutdown the Mill in the event of losing a roll because of a faulty repair, the decision to reclaim by welding was based on a careful assessment of all the relevant factors.

1. Weldability

In order to plan the weld repair it was essential to establish the weldability of the roll. Weldability is a measure of the steel's ability to make strong, sound welds and the factors which affect weldability are:

a) Chemical composition with weldability decreasing as the hardenability increases.

b) Heat input

c) Rate of cooling

d) Section size with the larger the component the greater the adverse affect on weldability.

d) Joint restraint, or, as in this instance, restraint between the weld bead and the roll.

Initially, laboratory scale tests were carried out to determine the fusion characteristics and the dilution/enrichment tendencies using, in the main, austenitic and austenitic/ferritic consumables. Pre and post heat treatment temperatures were established and the effect of various cooling rates examined.

The results showed conclusively that the complex air hardening alloy steel was weldable providing the heating and cooling rates were strictly controlled and the buffer and filler electrodes were selected with due regard to the chemical composition of the rolls.

2. Thermal Stress Gradient

An added complication to the repair was the inability to remove the drive-side bearings from the rolls. This meant that to prevent seizure the drive-side journal had to be kept below 100°C which would introduce a steep thermal gradient through the roll. This gradient could initiate thermal stress cracking in the bull-head pass. On assessment it was considered that

i) the tough core of the double pour roll could accommodate the thermal stresses which would build up slowly because of the controlled heating and cooling rates, and

ii) on cooling, after completion of the repair, the heat flow reversal from core to surface would subsequently relieve any stresses in the outer shell.

3. Welder Skill.

The repair could not have been contemplated without specialised welder skills. Fortunately two welders with the required expertise and technique compatibility were available. Technique compatibility was of major importance as the welding was a continuous process over a 76 hour time span.

The Metallurgy of the Weld Repair

The weld repair strategy was based on the elimination or control of

i) heat affected zone martensite;

ii) carbide concentration along the fusion line;

iii) hydrogen;

iv) restraining stresses.

These four conditions are the major obstacles to the successful welding of high carbon, high alloy steels and they are controlled by welding technique, electrode selection and thermal cycling.

Welding Technique

The shielded metal arc process was selected as being the most suitable welding method available and the technique evolved around the principle of minimum heat input and slow cooling.

Suitable buffer layers between the base roll and the hard facing filler were also of prime importance in order to ensure carbide free dilution and prevent restraint cracking.

Electrode Selection

Buffer Layer

The buffer layer must fulfil a number of functions, viz-

i) To minimise the effects of dilution and prevent a build-up of brittle carbides along the fusion line.

ii) To counteract the adverse effects of differences in co-efficients of expansion - contraction between the hard facing layer and the base metal.

iii) To have a high deposition rate to ensure a low heat input.

iv) The deposit must be ductile, tough and resilient to accommodate the restraining stresses and resist hot cracking.

In order to obtain optimum properties two buffer electrodes were selected.

Base Buffer Layer: UTP85FN, a low hydrogen ferro nickel electrode with high deposition efficiency was selected.

Reasons:

i) The roll microstructure of globular carbides in a tempered martensitic matrix necessitated a weld metal free from carbide formers and carbide stabilisers to ensure carbide free dilution.

ii) The co-efficient of expansion-contraction of nickel alloys is midway between that of ferritic and austenitic steels.

iii) A free flowing electrode with a high deposition rate which, in conjunction with a low current density, insures a low heat input. This is an important property in respect of welding an air hardening, high hardenability steel as it restricts the extent of the martensitic heat affected zone.

iv) The ferro-nickel weld metal exhibits toughness and good ductility.

Intermediate Buffer Layer: UTP63, a special fully austenitic electrode was used for this application.

Reasons:

i) Austenite exhibits good notch toughness, ductility and resilience.

ii) It has a high solubility for hydrogen which reduces the risk of cold cracking.

iii) It will inhibit the formation of heat affected zone martensite from the first run of the hard facing filler.

iv) The 7% manganese content will counteract the susceptibility of the Nickel Chrome austenites to solidification cracking.

Hard Facing Filler: UTP73G3, a low hydrogen electrode for high temperature resistent surfacings on hot worked steels exposed to impact, compression and abrasion was selected.

Reasons The properties of this electrode are ideal for the service conditions encountered in the hot rolling of ingots to blooms.

Thermal Cycling

The thermal cycle applicable to the welding of air hardening alloy steels is made up of a preheat, an interpass heat, post heat and controlled cooling.

Preheat

Preheating is a method of preventing hot and cold cracking and to be effective it must exceed 150°C, the temperature at which the solubility of hydrogen decreases, and with respect to airhardening steels, it must also exceed the temperature at which martensite will start to form, that is the Ms temperature.

This preheat temperature is normally accepted as 50°C above the Ms temperature which is obtained from the relevant isothermal transformation diagram. As the isothermal transformation diagram for this complex high carbon alloy steel was not available, the preheat temperature was estimated. The estimation was based on the fact that carbon and most alloys depress the Ms temperature and as the Ms temperature for a 0,95% carbon steel is approximately 190°C a preheat temperature of 200°C would, with a reasonable leeway, exceed the temperature at which martensite would form.

Interpass Heat

In order to retain the benefits of the preheat, the welding interpass temperature must be maintained until completion of the welding and the start-up of the post heat.

The interpass temperature slows down the expansion - contraction reaction between the base metal and the weld bead reducing the magnitude of the restraining stresses. It also prevents the formation of martensite in the H.A.Z.

Postheat

The purpose of the post heat is to achieve the desired properties by

a) preventing the formation of martensite by maintaining the temperature above the Ms temperature until the desired isothermal transformation reaches completion, or

b) decreasing the hardness and increasing the toughness of any martensite which had formed by postweld tempering, and

c) allowing time for the diffusion of hydrogen.

A postheat temperature of 400°C and a 20 hour dwell time at temperature was considered necessary to ensure the completion of the isothermal transformation which would give the required combination of hardness and shock resistance to the repaired roll.

The temperature was too low to initiate carbide precipitation in the austenitic buffer layer.

Cooling Rate

The cooling rate is always closely associated with the postheating and with respect to air hardening steels it is extremely critical. The cooling rate of the repaired roll was restricted to a maximum rate of 10°C per hour to prevent the formation of martensite.

Repair Procedure

Roll Specification

Make:	Gunternann and Peipers
Quality:	AS70
Dimensions:	Length 5,2m
	Barrel Diameter, Top Roll 1 050 mm
	Barrel Diameter, Bottom Roll 1 055 mm
Unit Weight:	Top Roll 19,2 tonne
	Bottom Roll 19,3 tonne
Maker's Description:	Double pour cast steel with low residual stresses in the core material. The shell material is an optimum combination of wearing properties, resistance against spalling and fire cracking, strength, toughness and favourable residual stresses.

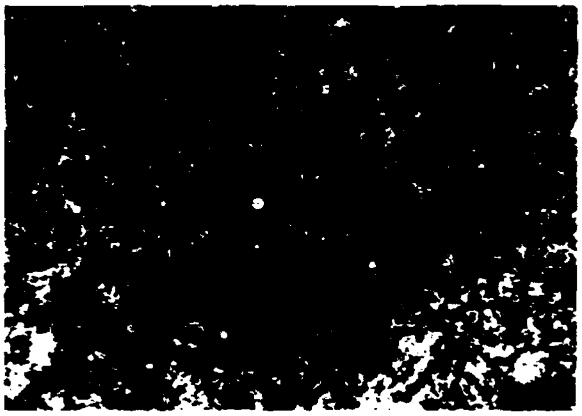
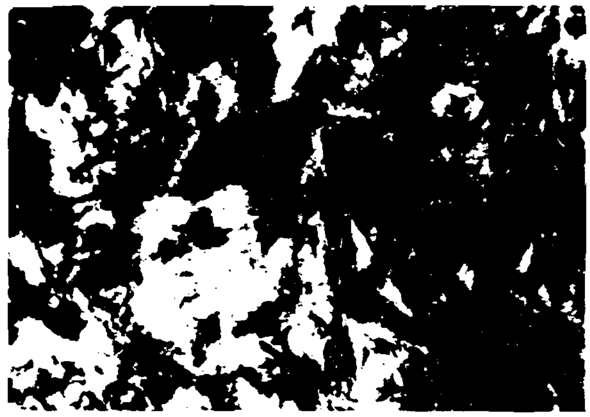
Chemical Composition (Actual)

C	Mn	P	S	Si	Cr	Ni	Mo	W
0,96	1,90	0,011	0,015	0,55	1,50	0,63	0,25	0,83

Hardness: Specification 58° - 63° Shore "C"

Actual 60° Shore "C"

Microstructure: Small, randomly dispersed globular carbides and retained austenite in a tempered martensitic matrix. The structure is illustrated in photomicrograph "A".

X 100 2% Nital Etch X 500

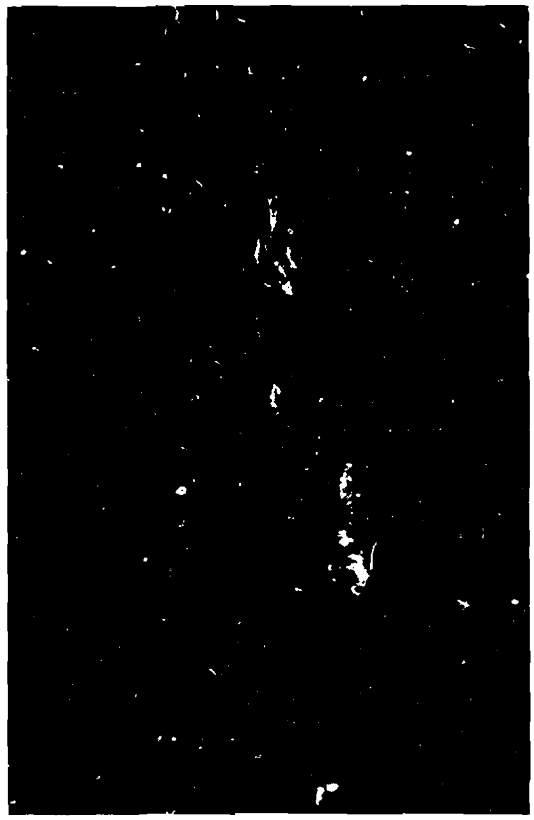
Photomicrograph "A": General roll structure

Roll Damage

A segment of the top roll collar between the 205 mm and 190 mm passes broke away. On inspection a matching segment of the bottom roll was found to be cracked.

The damaged areas were dressed by grinding preparatory to repair welding. The top roll collar damage, before and after dressing, is illustrated in Photograph 1.

Before Dressing



After Dressing

Photograph 1: Top roll damage

Welding parameters

The welding parameters were supplied by Guntermann and Peipers, the Roll Manufacturers, and confirmed the initial laboratory trials. Except for minor modifications the parameters were strictly adhered to.

Thermal Cycle

The method and control of the heating and cooling cycle was of prime importance. The roll was mounted on Vee rollers and rotated at 3 rpm through the chain driven rollers, Photograph 2.

Photograph 2: Chain driven rollers for rotating this roll.

An insulated hot box fitted with four propane-oxygen burners and a removable lid was built around the damaged collar. The remainder of the roll was lagged with Fibrefrax insulation wool. Due to the necessity to keep the drive side bearing journal cool, the bullhead pass was not insulated and this lack of insulation introduced the thermal stress gradient shown in figure 1.

The burners were off-set each side of the collar to prevent direct flame impingement and rotation of the roll ensured even and easily controlled heating and cooling. The general arrangement is shown in Photograph 3.

THERMAL GRADIENT

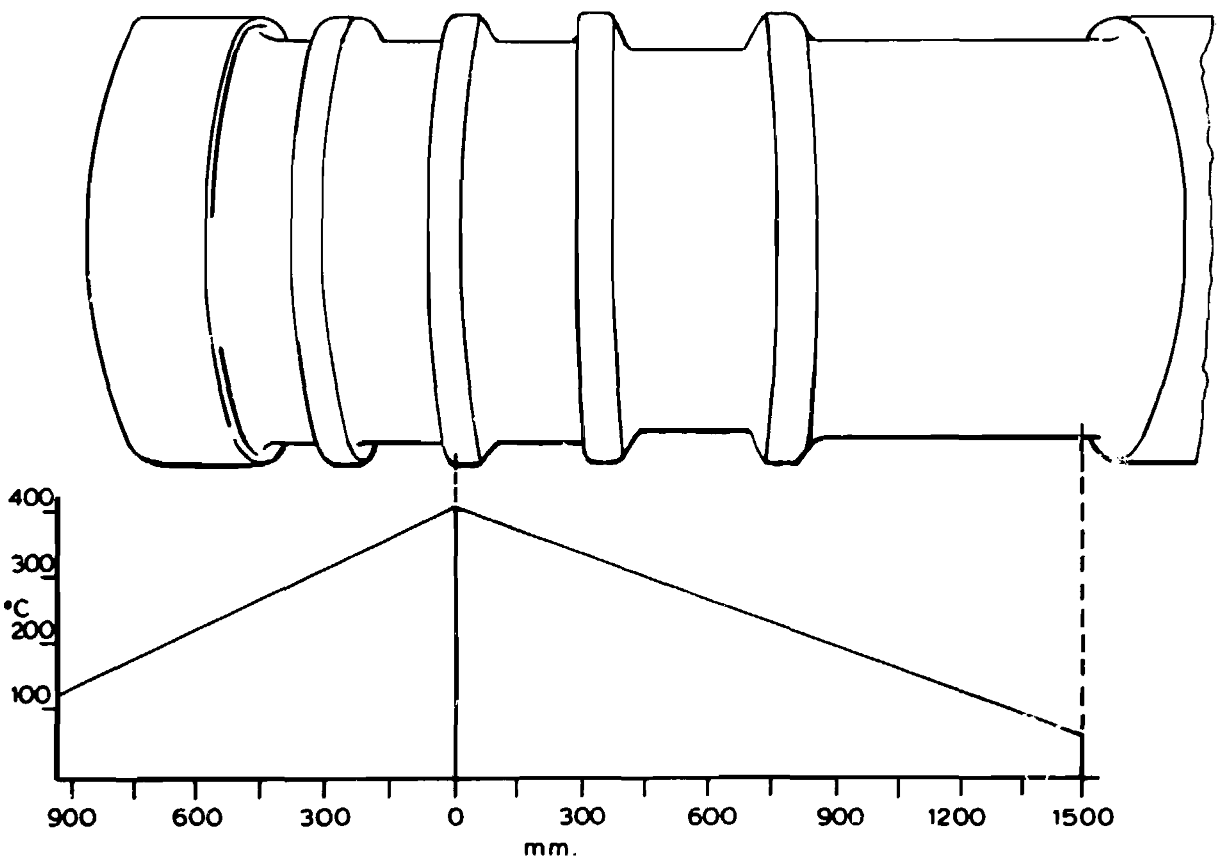
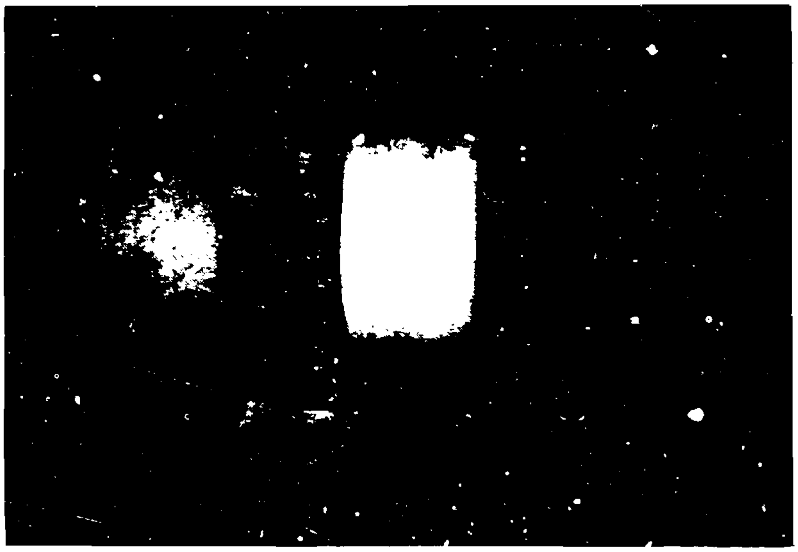


FIGURE 1 ... THE THERMAL GRADIENT THAT WAS INTRODUCED DUE TO THE INABILITY TO REMOVE THE BEARING.



Photograph 3: General arrangement showing hot box, burner positions, lagging and removable lid.

The welding thermal cycles for each roll are graphically presented in figure 2. Thermal crayons and a digital read-out contact thermometer were used for the temperature control.

Welding Technique

The weld repair technique is schematically presented in figure 3 and the statistics are listed below:

Position	Electrode Type	Total Weight Consumed (kg)
1st Buffer Layer	UTP85PN	4
Intermediate	UTP63	5
Hard facing filler	UTP73G3	

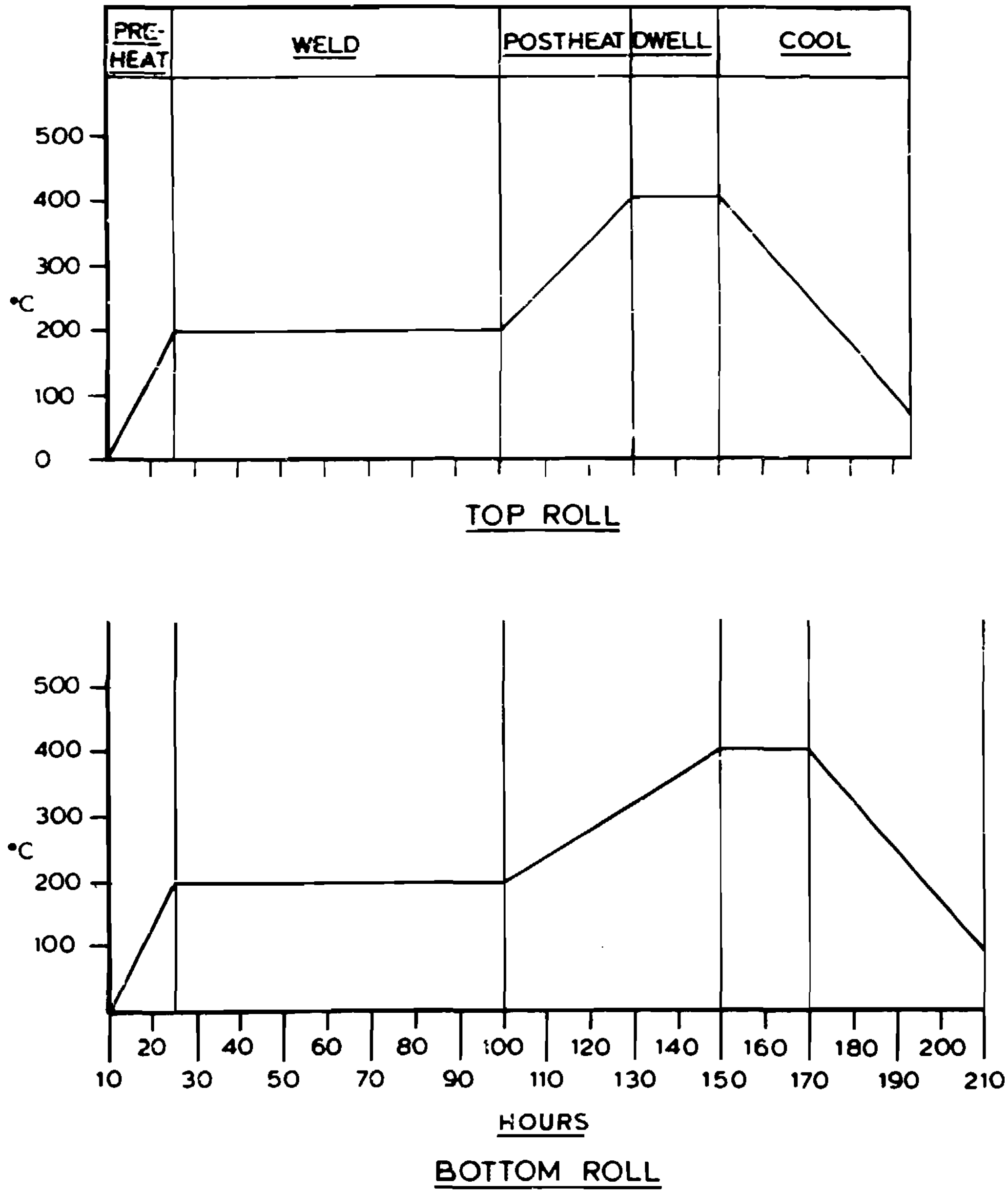


FIGURE 2... WELDING THERMAL CYCLES FOR EACH ROLL

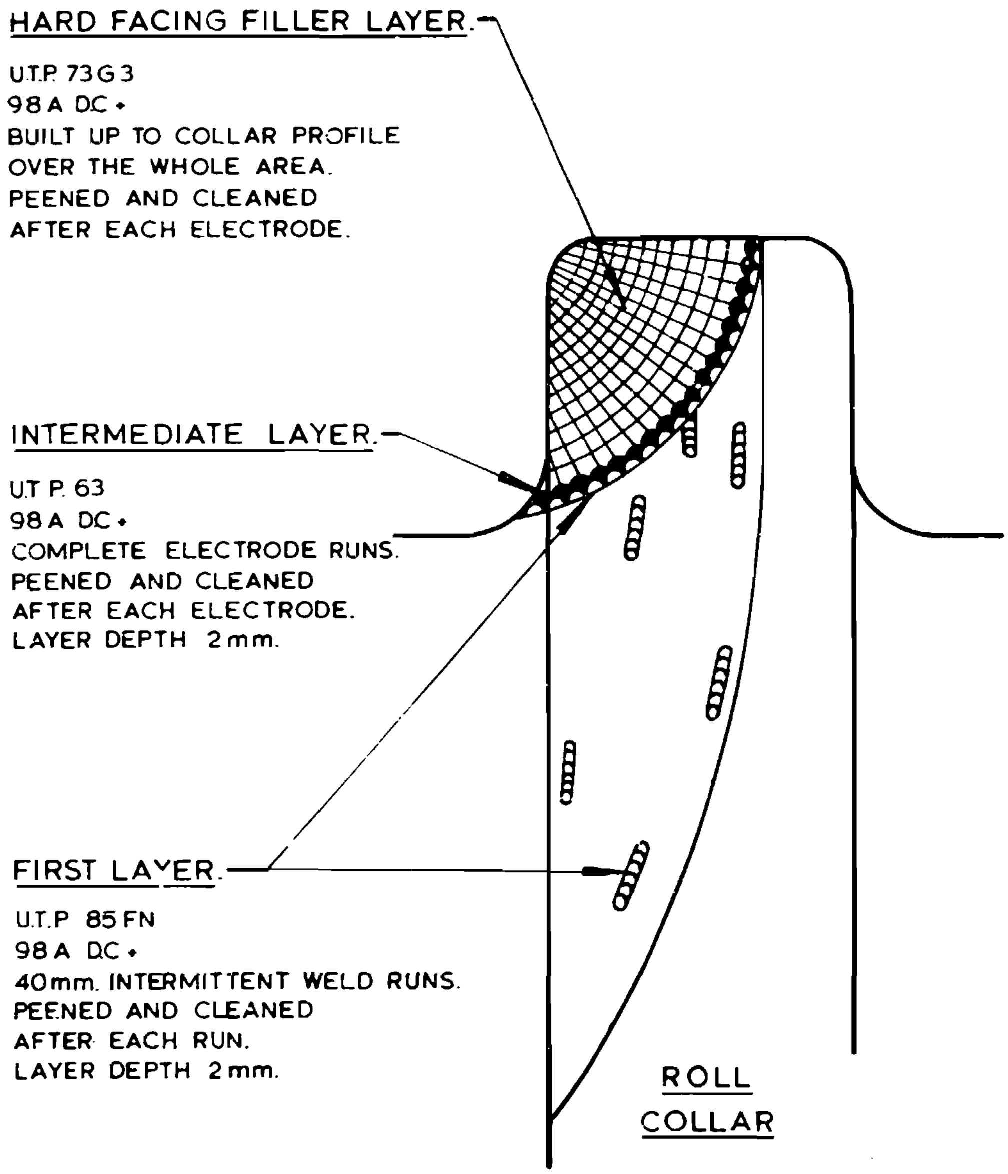


FIGURE 3... SCHEMATIC DIAGRAM OF THE WELD REPAIR.

Welding Technique - Continued

All the welding was carried out in the horizontal position, Photograph 4, by removing the hot box lid.

Photograph 4: Horizontal positional welding

The importance of hot peening

1) Restraining stresses evolved from the thermal expansion and contraction of the weld metal and heat affected zone against the restraint of the cooler mass of metal surrounding it. On heating expansion is constrained and compressive stresses are set-up while, on cooling, tensile stresses are induced during contraction as depicted in figure 4. Hot peening, Photograph 5. in conjunction with the preheat relieves these stresses and prevents hot cracking.

2) Hot peening of the intermediate austenitic buffer layer was carried out to prevent the precipitation of carbides in the grain boundaries.

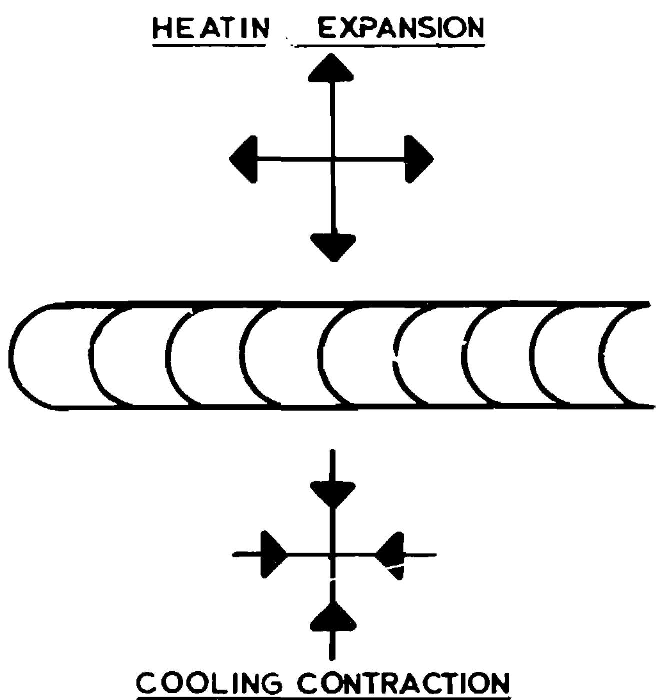
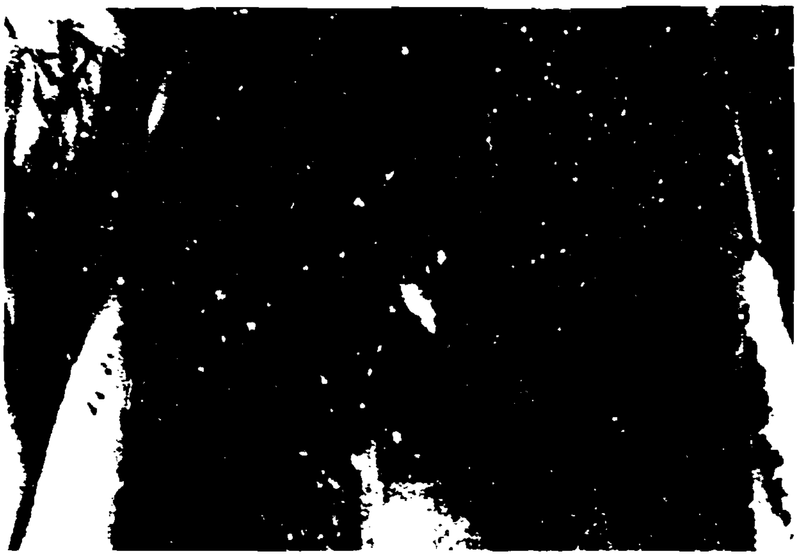


FIGURE 4 ...RESTRAINING STRESSES.



Photograph 5: Hot peening of the initial buffer layer, UTP85FN ferro-nickel type electrode.

Three stages of the weld repair are illustrated in photographs 7, 8 and 9.

Photograph 7: Complete weld build-up.

Photograph 8: Partially machined with the collar shoulder "as welded".

Photograph 9: Finished machined and penetrant dye tested which exposed light porosity.

Costs

Labour

	$
Total labour including extra roll turning hours due to the reduced machinability of the weld build-ups.	6 048,00

Consumables

Electrodes	1 269,20
Propane Gas	1 718,00
Millboard insulation hot box lining	244,00
Fibrefrax insulation wool	979,47

Miscellaneous

Hot Box Construction	66,00
Total Repair Costs	$10 258,67

Roll Life

Basic Cost per tonne of steel rolled on expected rolled life	0,071

If the weld repair had not been attempted the roll diameter would have required a dressing which would have reduced the roll life by 62%.

Cost per tonne on this basis would be	0,187

Cash recovery is therefore $0,116 per tonne rolled.

On a 677 000 tonne throughput the costs of the repair, plus an additional $68 000 have been recovered.

Weld Assessment

An "in situ" examination of the repaired rolls after 80 000 tonne: throughput revealed:

i) The weld build-ups were in excellent condition with the only signs of wear being isolated light grooving of the 85FN buffer layer on the collar shoulder as shown in photograph 6.

Photograph 6: Light grooving along the 85FN/UTP63 interface.

ii) The base roll was wearing preferentially to the UTP73G3 hard facing.

iii) Fire cracking and heat cracking was more severe on the base roll, the UTP73G3 hard facing being virtually unmarked.

iv) The weldments have successfully withstood severe impact loads, as indicated by the presence of a number of depressions and score marks.

Roll History

Campaign No.	Tonnage	Remarks at end of Campaign
1	90 973	Broken Collars weld repaired.
2	121 135	Welds in excellent condition, rolls wearing preferentially.
3	127 005	Welds in excellent condition. Machinability improved, no longer necessary to profile grind the weld deposits.
4	107 767	As for Campaign No. 3.
5	113 702	Weldment on bottom roll dressed out: only minimal weldment remaining on top roll.
6	105 888	The remaining weldment on the top roll dressed out
7	100 582	Both rolls dressed to well below weld line, 19% life remaining

Total Tonnage rolled to date, after weld repair 676 079

62% of guaranteed 800 000 tonne lives 496 000

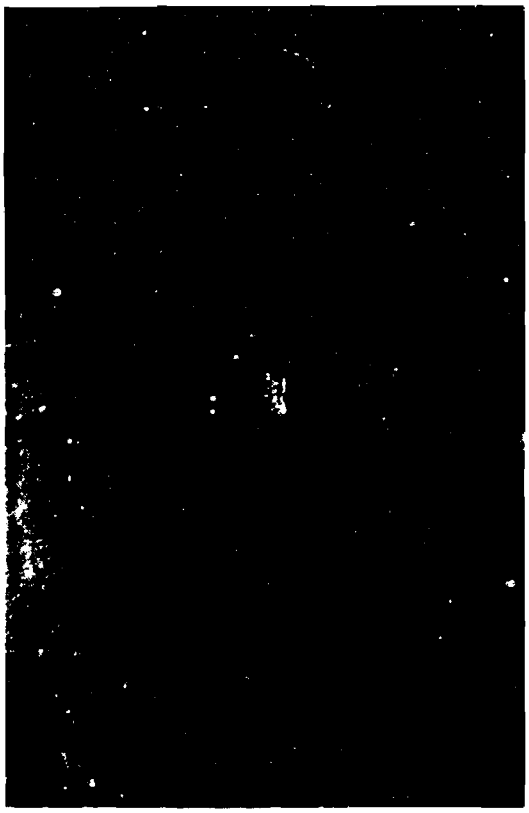
It is confidently anticipated, based on their performance to date, that the rolls will reach the 1 000 000 tonne throughput before reaching scrap size.

Discussion.

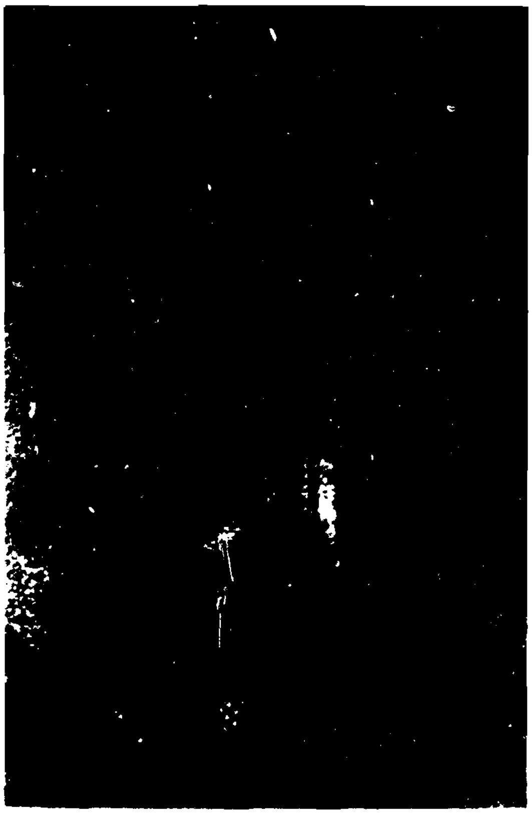
At the time of the damage it was calculated that the normal reclamation method of machining to below the fracture lines would have reduced the lives of the rolls by 62% or, in terms of production, approximately 500 000 tonne throughput.

In order for the weld repair to be 100% successful it was therefore necessary for the 44 kgs. of deposited weld metal per roll to withstand the very arduous service conditions imposed by the rolling of 500 000 tonne of steel at approximately 1300°C. To compound the normal rolling conditions encountered in a Cogging Mill an additional unforeseen complication arose. Due to the political changes which had taken place in the country the Company experienced an exodus of both rolling and engineering skills. Consequently the welded rolls were subjected to the unavoidable abuse inflicted by a succession of learner rollers. The deposits were, at times, dented and scored - the results of innumerable encounters with the learner rollers - but at no time did the welds either spall or crack.

The condition of the weldments on removal from the mill after the 5th Campaign is illustrated on the accompanying photographs.

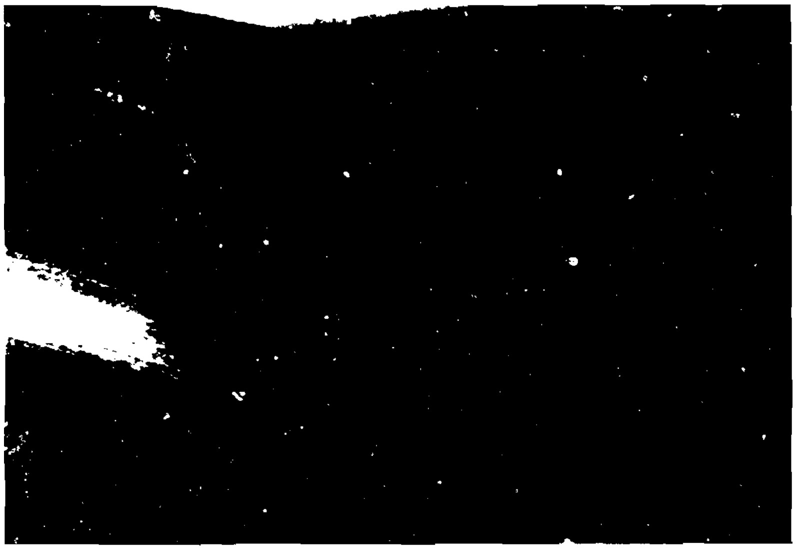


Top Roll



Bottom Roll

On dressing the bottom roll dressed clean whilst only a minimal amount of weldment remained on the top roll. All traces of the weldments were removed during the 6th dressing.



Top Roll
Weldment after 5th Dressing.

The fact that the welds have successfully withstood the abnormal and adverse rolling conditions imposed by unforeseen circumstances is tribute to the quality of the welds and the UTP consumables which, without fear of contradiction, exceeded their guaranteed properties.

Conclusion

The decision to weld repair the damaged rolls has been fully vindicated. the experience gained in this unique cost recovery exercise will generate confidence and more effort towards other reclamation projects of a similar nature.

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References

Metals Handbook, Volume 6.

The Metallurgy of Welding, Brazing and Soldering, J.F. Lancaster

U.T.F. Handbook

Welding of Plant and Tools, D.E. Jordan, Metallurgia, July 1980.

The Austenitic Electrode, C.P. Cookson, The Metallurgist and Materials Technologist, November 1975