

Surface Behaviour Of HSS In Hot Strip Mills

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Improvements associated with the introduction of High Speed Steel rolls to the finishing stands of Hot Strip Mills have long been appreciated.

Characteristics associated with the use of High Speed Steel materials are discussed here. A metallographic study of worn High Speed Steel surfaces is presented. This study is further developed to investigate the formation of oxides on the surface of High Speed Steel materials and to examine any related effects.

High Speed Steel rolls in service are investigated. The study presented identifies behavioural differences between roll materials and stands and incorporates visual observations and physical measurements.

Introduction

The introduction of cost reduction programmes and more stringent quality requirements over recent years to the flat products industry has led to demands from the roll users for improved efficiency. As a direct result areas targeted for attention have included:

- a) Roll wear and dressing requirements
- b) Lengths of rolling campaigns
- c) Roll surface quality and stability of oxide layers
- d) Gauge control

Such work has led to the manufacture of new roll materials one such being the development of High Speed Steel work rolls. The introduction of such materials to the early finishing stands of Hot Strip Mills has produced significant improvements in several of the areas listed above.

The Davy Roll Co has been developing this product since 1993 and rolls have been in service in various mills since 1995. This paper summarises some of the technical work that has accompanied the rolls throughout their service as part of the company's commitment to customers and continuous improvement.

Investigations have included the following areas:

1. Consideration of traditional surface features and those of worn HSS rolls focusing on surface deterioration and surface oxide behaviour.
2. Rolls in service including
 - A study of the evolution of roll surfaces and oxide formation throughout rolling
 - Oil lubrication and its effect on roll barrel surfaces.

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1. Roll surfaces

Background to Normal Surface Features

Many hot strip mills operate 6 or 7 stand tandem finishing practice. Traditional work roll qualities include High Chrome in the early finishing stands and Alloy Indefinite chill (AIC) in the last three stands.

Rolling conditions are aggressive. Contact with the hot strip and then air and water cooling systems not only generates severe thermal cycling but also leads to oxidation of the roll surface. These thermal effects are considered to be more severe in the early finishing stands, where strip temperature and contact time with the roll surface is at a maximum.

Exposure to such conditions produces 'fire-crazing,' a feature defined as a fine network of cracks normal to the roll surface. It has been observed that crazing is initiated at and follows carbide sites. Coarse localised surface cracking, with cell sizes greater than 2mm^2 , is generally referred to as 'fire-cracking' and results from abnormal and excessive thermal conditions. Both features are illustrated in figure 1.

A second form of cracking occurs parallel to the roll surface due to Hertzian stresses resulting from contact with the back up roll. The intersection of the two types of cracking leads to near surface disintegration as illustrated by AIC roll material, in figure 2.

Breakdown of the oxide layer as circumferential strips or 'bands', termed 'Banding' within the industry, generally accompanies surface disintegration. Although several mechanisms have been proposed for this process, work at Davy Roll suggests that banding follows crazing of the roll surface and cracking of the carbides within the microstructure. These oxide bands peel from the roll surface, initiated by fragments of roll material which break away from the main metal substrate.

Banding generates several problems of concern to Steel producers. Poor strip quality is often associated with rolled in scale (stripped oxide) and uneven gauge. This is sometimes compounded by additional or premature roll changes due to roughened barrel surfaces. Changes in mill operating parameters such as increases in power consumption have also been reported.

Introduction of HSS

The development of High Speed Steel materials in the last decade has represented a major advance in roll technology. Such materials have demonstrated dramatic improvements in roll wear resistance and strip quality and extended rolling campaigns. Investigations into roll characteristics have attributed this success to improved mechanical properties – see Table I, harder and more wear resistant carbides and a strengthened matrix.

Table I

Material	Tensile / N/mm ²	
	Ambient	Hot – 600°C
AIC	345	238
HiCr	850	549
HSS	850-1100	700-800

In general, HSS shell materials are based on combinations of carbon, chromium, vanadium, molybdenum, tungsten and sometimes niobium and cobalt.

It has been proposed that the properties exhibited by HSS materials arise from the production of a series of complex carbides (MC, M2C and M6C) and that in addition, Cr, V, Mo and Co preserve matrix hardness (predominantly martensite) at high temperatures (1,2,3).

It has further been suggested that optimum mechanical and physical properties are predominantly derived from a combination of the harder carbides. Research has shown that successful development is dependant on optimising concentrations of MC and M2C carbide forms with minimal M6C, this balance predominantly controlled by the material chemistry (2,3) – see table II.

Table II

Carbide type	Metal Element	Hardness / Hv
M3C	Fe-Cr	840-1100*
M7C3	Cr-Fe	1200-1600*
M6C	Mo-W-Fe	1650
M2C	Mo-W-Cr-V	2200
MC	V	2800

*Predominant carbide types for AIC and HiCr respectively.

It has been stated that there is a need for a controlled balance of matrix and carbide hardness. If the matrix hardness is excessively less than that of the carbides, there is a possibility of severe uneven wear. The matrix will be seen to wear away rapidly leaving carbide protrusion at the surface. This feature is considered to greatly affect roll frictional characteristics and associated mill operating parameters. Furthermore it has been noted that certain shell chemistries produce microstructures with high concentrations of the brittle M2C carbide which has been identified as having poor crack resistance(2).

The Davy Roll Co considered many grades of HSS material, three of which have been supplied to various mills. With each introduction into the mill environment, the questions of surface break down and oxide nature have been raised.

The Davy Roll Co has investigated roll surfaces at every available opportunity in order to provide a technically based response to the customer. The following summarises some of our findings.

Experimental

Several areas on the barrel surfaces, which exhibited significant concentrations of oxide, were identified and sampled for each case studied. Samples were sectioned in the rolling direction and across the rolling direction looking longitudinally along the roll.

Rolls sectioned and reported here, are all understood to have experienced similar mill conditions.

- Figures 3, 4 and 5, in the direction of rolling, show oxide as a semi continuous layer along the surface of the sample. Depth of oxide appears to be related to grade of material, with the earlier grades showing the thickest and possibly most adhesive films. It was noted that the oxide of the first grade of material exhibited the greatest number of 'normal' cracks, this perhaps a function of thickness. The severity of oxide cracking may be a significant factor in that it could represent a mechanism for the generation of 'normal' crazing. It has been proposed that strong adhesive forces might permit cracks in the oxide layer to propagate into the metal substrate. This statement has important implications in that depth and stability of oxide layers are considered to influence roll performance and strip quality.

- Figures 3, 4 and 5 also demonstrate the result of abrasive wear in the form of oxide filled grooves. This again appears to be more pronounced in the earlier grades, a feature possibly connected to lower hot hardness values. Figure 3 also shows shallow cracks originating from the base of the oxide layer and travelling along carbide-matrix interfaces. This is considered to be either a specific characteristic of this particular material or a mechanism for the extension of surface cracks. Subsequently, it has been suggested that the features observed might result from a combination of thermal conditions and a wedging action of hard oxides –see Table III (5). The consequence of oxide flow or convergence is also shown in figure 3 as entrapment and subsequent displacement of fragments of roll surface.

Table III

Oxide	FeO	Fe ₂ O ₃	Fe ₃ O ₄
Hardness / Vickers	300	1000	450

- X- ray diffraction of roll surfaces has shown that the different shell compositions do not affect the basic nature of the oxide, being identified as predominantly Magnetite (Fe₃O₄), with a minor amount of Wustite (FeO) detectable in the earliest material. This is in good agreement with predicted oxide kinetics(6) which suggests a prominence of Fe₃O₄ at iron rich-oxygen deficient interfaces and variable concentrations of FeO and Fe₂O₃ . The concentrations of the latter are said to be dependent on the ease of ion and electron movement through the oxide layer and rolling environmental conditions.
- SEM and EDAX spectroscopy of the oxides has highlighted the presence of chromium and variable amounts of vanadium and molybdenum, again a reflection of the different shell compositions. Further analysis, has revealed the Fe matrix to contain only the additional oxide 'metals'. This would infer that Cr, V and Mo are carried through to the roll surface on oxidation of the matrix material. The effects of the 'contaminating' alloys are not fully understood, however it has been suggested that certain elements influence the plastic(3) and adhesive nature of oxides and their resistance to banding(4).
- Figures 6, 7 and 8, (across the direction of rolling), show far deeper and more extensive examples of crazing 'normal' to the surface. Secondary branching initiating from these cracks can also be seen across all HSS grades, a result of Hertzian stresses. Close examination of figures 6, 7 and 8 shows that the oxide is able to extend into the body of a crack, possible evidence of plastic or 'flow' behaviour under certain conditions. In addition figure 6 indicates the final outcome of crazing and oxide 'flow'. It can be seen that when the parallel cracks lined with oxide intersect with 'normal' crazing, the surface will begin to crumble.

Overview

HSS has been shown to suffer from the same tribological processes as traditional roll materials. Comparison with traditional materials has indicated that HSS materials exhibit oxidation, and especially, crazing to a less severe extent.

Examination of sections in the direction of rolling has revealed surface oxide layers of variable depth and penetration into the metal substrate in the form of wedges, the severity of both features appearing to be related to grade of material. The implications of these features have not been fully resolved. However, it is understood that oxides that continue to build to significant depths before banding occurs tend to produce extremely roughened surfaces unsuitable for further service. It might be concluded from this statement and the experimental observations that the latter grade of HSS material will generate the most optimum rolling surface. We would propose that it will not only produce sufficient oxidation to maintain a protective barrier from the strip, it will also exhibit reduced micro spalling from oxide damage and could benefit from the 'repair' or oxide regeneration as suggested by Lanteri et al(7).

Following this discovery it was suggested that the sharp angular oxide filled cracks, might not be associated with the roll surface damage or the degradation process and were possibly residual grinding marks from the dressing process filled with oxide. Subsequent surface samples were taken

from areas outside the rolling path. Figures 9 and 10 show good roll surfaces with no evidence of oxide or any surface scoring. It was concluded that the features described result from the rolling process and are probably related to the surface degradation process on a micro scale.

Micros taken across the direction of rolling have shown numerous examples of oxide filled cracks. Consideration of the features displayed by both planes lead to the theory that initially crazing occurs longitudinally. This theory has been confirmed in this investigation by further examination of roll surfaces. Figure 11, shows that crazing has only occurred in a longitudinal direction.

The reason why crazing does not occur simultaneously in both planes is not yet fully understood, however we would like to propose that the surface either:

1. Initially benefits from a geometric effect generated by the oxide filled grooves, which for an indeterminate period of time allows surface deformation, without necessarily causing 'normal' crazing.
2. Or that, the extension of 'normal' crazing, results from a 'wedging' action of hard oxides as it intersects with carbide-matrix interfaces, but only when the oxide layer possesses a specific physical property and thickness.

2. Rolls In Service

Background

The introduction of HSS rolls to hot strip mills in the early nineties has been marred to some extent by the occurrence of a number of problems. Roll users, when comparing HSS to traditional Chrome qualities, have complained of:

- Cracking,
- More frequent incidences of oxide banding and subsequent strip defects
- Variable increases in rolling forces.

As a result, various groups in conjunction with several HSMs, have conducted investigations into:

- Chemistry and metallurgy of roll shell materials
- Rolling parameters including, strip temperature, rolling speed, reduction rate, roll and strip water cooling and roll lubrication

Trials were conducted under typical High Chrome conditions, which revealed that modified water cooling systems have the greatest influence on many of these parameters. In particular, the application of inter-stand water-cooling appeared critical to obtaining the maximum potential of HSS rolls. Once base line operating conditions had been established, attention focused on the behaviour of HSS in service and increasing their output.

The Davy Roll Co has been involved in production trials on many occasions and has monitored roll surface performance. The findings of some of these trials are summarised below:

A Study Of The Evolution Of Roll Surfaces And Oxide Throughout Rolling

These trials were conducted at BSSP Llanwern Hot Strip finishing mill and focused on the first three stands - F1 to F3. Conditions were based on normal HiCr roll practice with an 'Intermediate' roll change on selected stands and a 'General' roll change on all stands. In addition to examination at the start and finish of each campaign, rolls were withdrawn and assessed at various intervals between runs of 21 and 156 bars. From these observations a number of features were identified.

- HSS rolls entering service had ground finishes of the order 0.1 to 0.7 Ra um. Measurements during campaigns showed that barrel surfaces would begin to build up a smooth oxide layer (0.2 – 1.2 Ra um) which could roughen up to a level of 3.5 Ra um, before it began to breakdown. On breakdown the exposed roll surface was initially rough but then began to become smooth again.
- Subsequent withdrawals found that these smoothed areas often began to show evidence of oxide regeneration.
- Incidents of fire cracking did not necessarily affect oxide integrity. The oxide seen on rolls displaying localised longitudinal bands of fine fire cracking before service did not always show a tendency for more frequent or earlier banding.
- The condition of HiCr rolls after similar service were also noted for comparison. Overall, HiCr rolls experiencing similar production conditions exhibited poorer oxide coatings with greater incidents of stripping. Roll surfaces were seen to begin to deteriorate earlier in campaigns and often required replacing at the expected roll change.

Oil Lubrication And Its Effect On Roll Barrel Surfaces

A number of hot strip mills have experimented with oil lubrication for both HiCr and HSS rolls in the early finishing stands. Examination of roll surfaces associated with such trials led to various observations.

- With oil lubrication, a 'shiny black' oxide is seen to form very quickly, often within just a few bars. As the strip widths increase, so the oxide width appears to follow it. With the subsequent decrease in stock widths as the round progresses into its latter stages, the widest oxide deposits are no longer contacted by hot strip and appear to rapidly begin to show one, or a combination, of the following features:
 - Deterioration of the shiny black oxide to a matt grey appearance
 - Band(s) of circumferential slivers of oxide removal
 - Circumferential bands of stripping

All 3 features can occur on one roll.

- Some evidence of oxide flow has been seen in the form of comet tails and ' wavy oxide lines.
- It was generally observed that rolls without oil but adjacent to the stand being lubricated, regardless of whether they were HSS or High Chrome, showed a higher tendency to strip and roughens than those with oil. Whether this was due solely to the use of oil lubrication on the 2nd stand, or the higher rolling loads and temperatures encountered on stand 2 was unclear.
- Within the same observation period, rolling without oil lubrication predominantly produced an oxide with a matt grey appearance as opposed to the shiny black finish of the oil trials. In addition these rolls appeared to show a slight increase in surface roughness and an earlier tendency for the oxide to start to breakdown.

- The condition of HiCr rolls without lubrication were also noted for comparison. In general these appeared very similar to that of HSS rolls without oil lubrication but they demonstrated an earlier tendency for oxide breakdown and stripping.

Overview Of Trials

The Llanwern trial demonstrated that HSS rolls can perform extended periods of service without the need for dressing. HSS roll surfaces have shown a reduced tendency for oxide breakdown, lower roughness measurement and the ability to regenerate the oxide coating after incidences of banding. This represents an important financial implication for strip manufacturers. Mills removing rolls at intermediate roll changes may not benefit from the full potential of HSS rolls and could miss out on significant reductions in mill down time. Reduced roll wear and dressings will also bring obvious savings. On a down side it has been reported that frictional conditions for HSS rolls are higher than those for HiCr, resulting in an undesirable increase in power consumption. Some of the observed lubrication trials were initiated in an attempt to reduce power requirements as well as produce surface improvements. Indeed increased interest in lubrication has arisen from the use of HSS rolls.

Observation of lubrication trials demonstrates that oil lubrication, whether it be mineral or ester based, does not impair the barrel surfaces over standard or extended roll service. In fact oil lubrication appears to have a positive effect on the nature of the oxide coating, with a change in sheen and colour and reduced tendency to strip.

Conclusions

- HSS performance improvement has been considered in terms of surface deterioration mechanisms and oxidation.
- Specific surface damage features have been observed microscopically and causes considered.
- Observations of HSS rolls during rolling campaigns at BSSP Llanwern have demonstrated the ability to overcome roughening and reduce oxide peeling, suggesting that the full potential is not yet being realised.
- Various observations made during trials with oil lubrication suggest oil can have a positive influence on oxide features and surface roughness.

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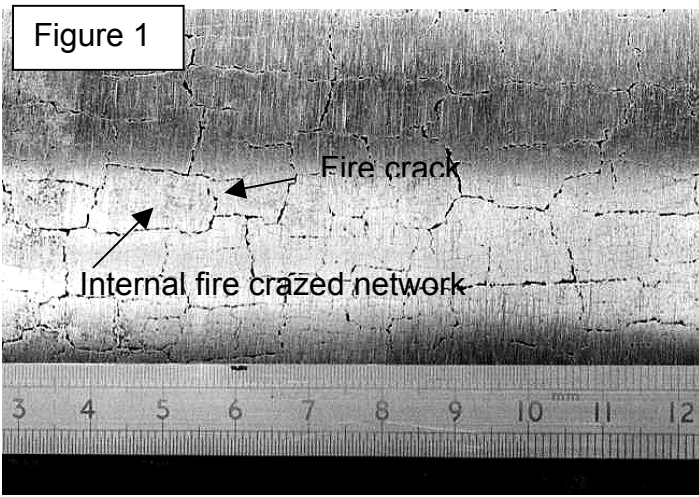


Figure 2

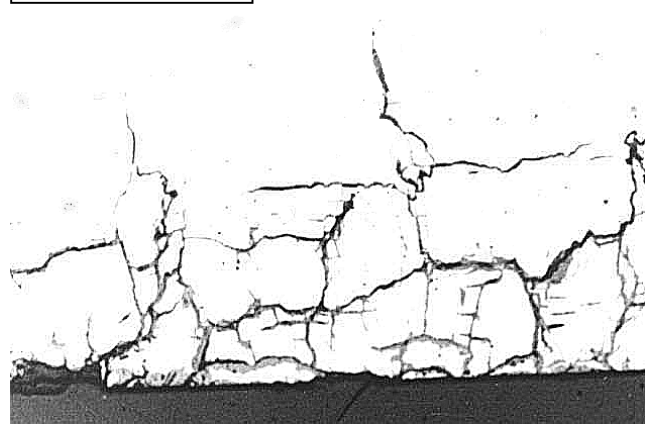


Figure 3 x800

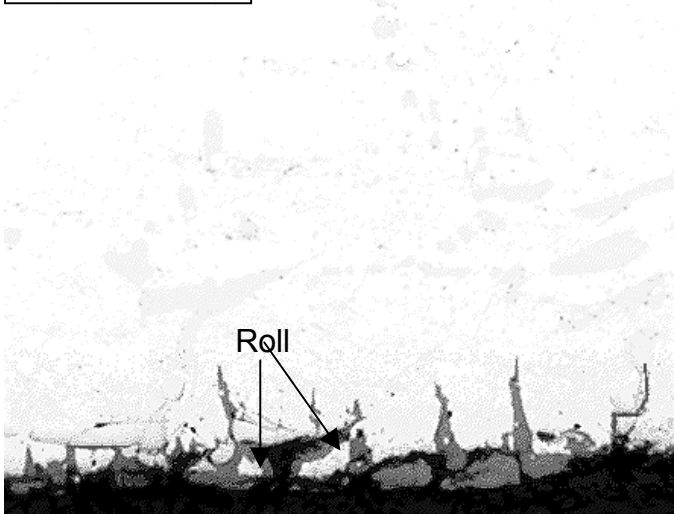


Figure 4 x800

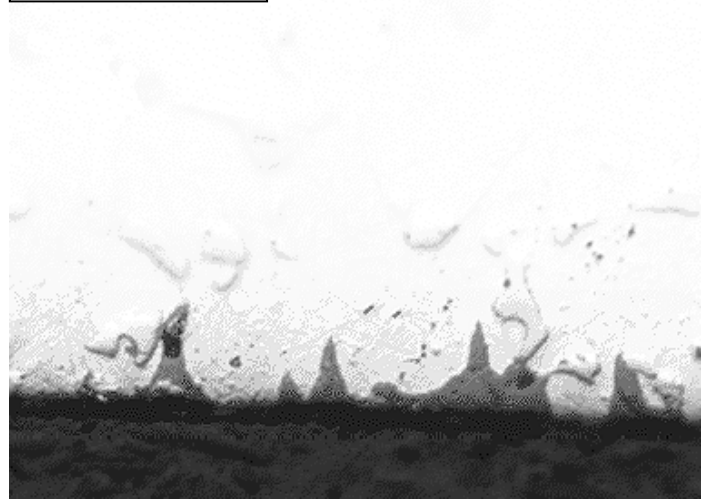


Figure 5 x800

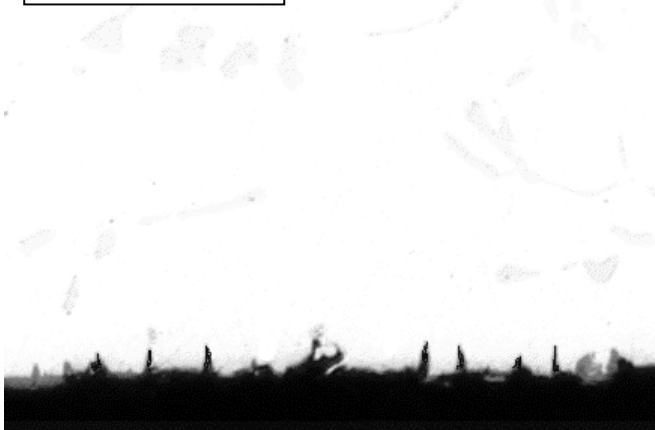


Figure 6 x160

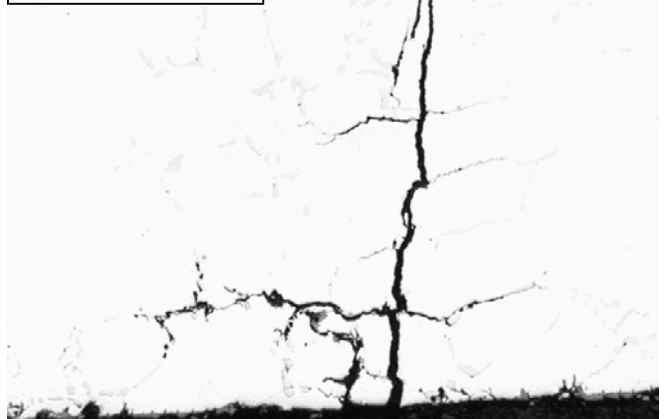


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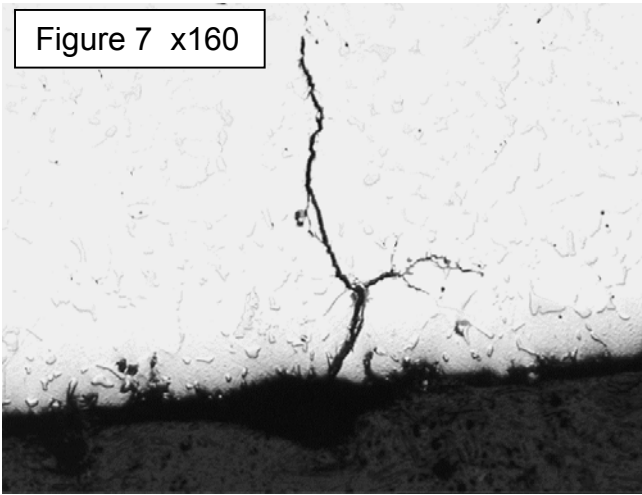


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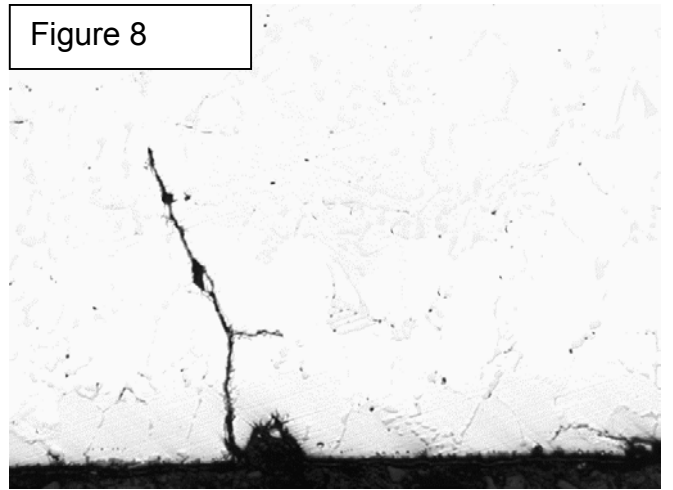


Figure 9

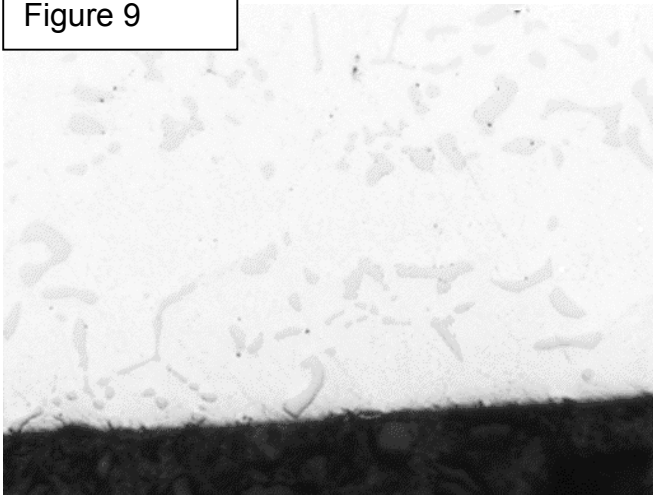


Figure 10

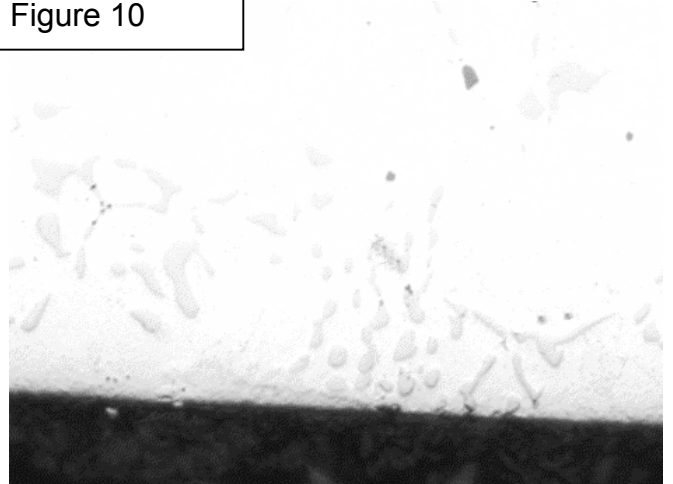


Figure 11 x50

