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TO: BELZONA POLYMERICS LTD

ATTENTION: DAVE BLACKWELL

SUBJECT: SECMET REPORT 1591

FROM: JOHN GREYSON

02 SEPTEMBER 1999

DAVE,

HEREWITH PLEASE RECEIVE THE COPY OF THE SECMET REPORT WHICH I HAVE DISCUSSED WITH YOU TELEPHONICALLY.

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BEST REGARDS.

JOHN GREYSON

TECHNICAL REPORT

SecMet (Pty) Ltd
Metallurgical and Corrosion Consultants

SecMet (Pty) Ltd

THE BELZONA 1591 PROTECTIVE COATING SYSTEM EVALUATION APPLICATION : HOT QUENCH OVERHEAD TRIM COOLERS

Client ref: Bel1591_99sn

Equipment: Hot quench overhead trim coolers

Prepared for: Gavin de Klerk

Author: S Nana **Date:** 16 August 1999

Approved by: JJ Wessels **Date:** 16 August 1999

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EVALUATION OF BELZONA 1591 FOR APPLICATION IN THE HOT QUENCH OVERHEAD TRIM COOLERS: SYNTHOL

1. INTRODUCTION.

SecMet (Pty)ltd was requested by Corrotech Coating to evaluate the Belzona 1591 coating system at elevated temperatures for application at in the hot quench overhead trim cooler assembly.

2. BACKGROUND

SecMet (Pty)Ltd assists clients in selecting the proper coating system for their environment and in the preparation or review of specifications. Coating system recommendations are based on past experience or through comparative testing in the laboratory or field. Corrosion detrimentally effects structures, reducing section thickness and resulting in a weakened structure that compromises safety. Corrosion control is normally achieved by applying a protective coating system to the steel structure. Unfortunately, coating systems do not completely protect and have limited durability. Moisture vapor penetration, water absorption, stress from thermal gradients across the coating and cause it to fail prematurely. Furthermore chemicals and salts from the atmosphere can penetrate the coating and allow corrosion to occur at the steel substrate underneath the seemingly intact coating, causing premature blistering and delaminating.

Coating properties: general discussion

The protective coating's function is to prevent corrosive service environments from contacting the underlying steel substrate and initiating corrosion. To accomplish this function, a coating must have several properties essential to maintaining a proper barrier to the environment. Some of the more important properties are: water permeability resistance, weathering resistance, sunlight resistance, ease of application, good adhesion, and good abrasion resistance. As noted, an important property of a coating is its resistance to water penetration. Two related properties are coating dielectric strength and coating resistance to ionic movement. Water can penetrate a coating either as a liquid or as a vapor. Water penetration decreases the dielectric strength of a coating, decreasing its resistivity and making the coating less insulative. Water penetration can also cause chemical breakdown of the coating. Moisture also transports oxygen that is necessary for corrosion to occur. Since corrosion is an electrochemical process, ionic and oxygen transport toward the steel substrate increases the chance of corrosion being initiated. Once corrosion has begun, the corrosion products formed can cause undercutting and loss of adhesion of the coating. Water penetration may swell the coating and produce stresses that eventually lift the coating from the substrate. Although water containing naturally occurring salts penetrate coatings at a slightly slower rate than pure water, their presence increases the likelihood of coating deterioration and substrate corrosion, since they can accumulate underneath the coating, cause delaminating by blistering, or accelerate corrosion of the substrate.

The coating proposal

Coatings system and manufacturer:

Sample test panels of plant applied coating systems were supplied by the coating manufacturer, applied according to the application procedures from the coating suppliers. This ensured that the application was indicative of the supplier's normal coating procedures and the applied samples were truly representative of the product being tested. Coating systems and manufacturer's are given Table 1.

Table 1. Belzona 1591

COATING SYSTEM	MANUFACTURER	APPLICATION
Belzona 1591	Belzona	Overhead trim coolers

Table 2. Belzona 1591 system breakdown.

Coating system	Coating sequence	Belzona specification	Surface preparation substrate
1. Belzona 1591	Two component system	Refer to Appendix 1	Sa 2.5 in conformance to the SP-80-2 specification.

3. VISUAL EXAMINATION

All the test panels received were visually examined prior to any testing according to BS 381C. The coating characteristic and substrate over which it was applied is given in Table3.

Table 3. Visual examination of test plate condition.: Belzona 1591

Coating system	Color	Application as-received sample	Remarks
Belzona 1591	Semi-gloss dark brown to black	Brush applied	1. Non-uniform ripple finish. 2. Runs and sags evident. Figure 1.

3.1 General characteristics of 1591 coating system:

Table 4. Characteristics :Belzona 1591

Coating sequence	Characteristics
Belzona 1591	"1. This system is used for high temperature equipment handling water, aqueous solutions and hydrocarbons. 2. Corrosion protection in immersed conditions at temperatures in excess of 180 °C"

4. COATING SYSTEM TEST METHODOLOGY:

The scribing protocol: ASTM D 1654

This protocol provides a means of evaluating and comparing basic corrosion performance of the substrate and the coating system, after exposure to corrosion environments, adopting ASTM standard D 1654.

Adhesion testing: ASTM D4541

The adhesion of a protective coating system to the substrate is considered to be a good indicator of the coating's ability to resists corrosion and therefore represents the longevity of the coating. Generally the better the adhesion, the longer the coating will last. Adhesion testing determines the "pull-off" strength of a coating system by determining the perpendicular force that the tested material will withstand before either releasing from the steel surface or pulling apart cohesively.

An alcometer adhesion tester was used to evaluate the adhesive properties of the coatings. To quantify bonding strength between the coating and the substrate, ASTM standard D4541 was employed. Aluminum dolly's were glued onto the paint surface(as-received condition), allowed to cure for 24 hours, after which the "pull-off" strength of the coating was appraised. Table 5. lists the average values of the adhesion of the coating system to prepared steel samples. All reported values represent results that should be found under ideal or laboratory conditions.

Table 5. Adhesion results of coating systems.

COATING SYSTEM	ADHESIVITY RESULTS(MPa)	Failure mode
Belzona 1591	5.5	Glue failure

Table 6. Adhesion test of coating systems after test protocol.

COATING SYSTEM	ADHESIVITY RESULTS(MPa)	Failure mode
Belzona 1591	5.0	Glue failure(de-cohesion)

Comment : The system displayed excellent adhesivity.

Dry Film evaluation - total dry film thickness (DFT): ASTM D1186-87

The dry film thickness (DFT) of a coating is an important coating property. Uniformity of the coating system may be gauged from thickness readings taken at various locations on the cured test panel. A uniformly applied coating, conforming to the manufacturers recommended DFT will be better equipped to provide a protective barrier to the substrate over which it is applied. Paint thickness measurements were carried out on the as-received test panels. The DFT of the coatings was determined according to ASTM D1186-87.
Test procedure: The test method covers the measurement of DFT of coating applied to a ferrous based metal. An average of 10 reading were taken using the Quanix 1500. Readings were taken approximately 25mm from the edge of the sample and the results are given in Table 7.

Table 7. DFT of as-received samples.

Coating system	Average DFT(μm)	Std. Deviation	Manufacturers specified DFT(μm)
Belzona 1591	680	76.18	800 to 1000

Comment: DFT's of as-received test plate coating system is below the manufacturer's specification.

Flexibility Test (ASTM D522).

The ASTM D522 test method is a good indicator of a coating system to withstand the cracking, disbonding, or other mechanical damage of the coating that can occur from handling and bending. The results of the flexibility test are given in Table 8

Table 8. Results of flexibility tests (ASTM D 522): as-received plates.

Coating System	Average flexibility
Belzona 1591	55°

Comment : Coating system displayed satisfactory flexibility properties on as received test plate.

5. ACCELERATED CORROSION TEST PROTOCOL

Full immersion and vapor phase testing: Water/steam

An experiment involving continuos immersion in water and vapor phase was chosen for accelerated testing because it provides a rigorous environment that accelerates degradation of a coating system. The test method employed the immersion of scribed test panels in water/steam at an elevated temperature at 160° C . The test was carried out in an autoclave, allowing for temperature and pressure regulation as well as to allow sealing off of the test environment from external imposition. The test parameters are given in Table 8.

Table 8. Test parameters :

Parameter	Condition
Operating temperature	160 °C
Operating pressure:	10 Bars
Operating medium: 1. fully immersed 2. Exposure to vapor zone	Water/steam
Duration of test	600 hours
Temperature cycling	From 160 °C to ambient after 150 hours and full ramp to desired temperature; 160 °C.
Agitation	Continuous

6. RESULTS

Evaluation methodology and tested system

Table 9. Evaluation of Belzona 1591

Coating system	Rust breakthrough	Blistering	Disbondment from scribe	Under film corrosion
Belzona 1591 *fully immersed*	yes Along exposed scribe (restricted)	no	no	no
Belzona 1591 *vapor zone*	yes slight rust formation on scribe	no	no	no

Table 10. Characteristics of coating after testing.

Coating system	Color	Remarks	Illustration
Belzona 1591 fully immersed	brown rust stained	1. Copious amounts of rust formation at scribe indicating media to be corrosive.	Figures 2,3
Belzona 1591 vapor zone	brown	1. Superficial rust formation evident along scribe.	Figures 4,5

Metallographic Examination.

Sections of the coated panel were cut transverse to the scribe. The samples were mounted in resin, polished, and evaluated. The results are given in Table 11

Table 11 Coating system cross section morphology:

Coating system	Characteristic of post test panel	Illustration
Belzona 1591 fully immersed	Coating intact to substrate, good adhesion characteristics Coating intact, no discontinuities evident. Corrosion of substrate evident at scribed area. Oxide spinel's evident	Figures 7, 8

Coating system	Characteristic of post test panel	Illustration
Belzona 1591 vapor zone	Coating intact to substrate. Corrosion on scribe was minimal in the vapor zone	Figures 9, 10

Scanning Electron Microscopy(SEM)

Energy dispersive x-ray(EDX) analysis is found to be a valuable laboratory tool when used in combination with a SEM to analyze sectioned test plates. The method, although semi-quantitative, is rapid and very informative. Thus, the presence of elements found in the most common pigments and contaminants can be determined.

Table 12. SEM evaluation of cross section of coating system .

Coating system	Characteristic of post test panel
Belzona 1591 fully immersed	Coating intact to substrate, good adhesion characteristics corrosion attack on scribe.
Belzona 1591 Vapor zone	Coating intact to substrate, good adhesion characteristics

An EDAX analysis was performed on the scribed area of the fully immersed test plate. The average results are presented in table 13

Table 13. EDAX analysis of product in scribe region.

Element	Average wt. %
Iron	74.56
Oxygen	25.44

Comment: The analysis on the product on the scribe corresponds to Iron oxide (Fe_2O_3).

7. DISCUSSION

Basic discussion on corrosion during test protocol.

Corrosion is an electrochemical process involving the anodic oxidation of the metal to

ferrous ions, followed by oxidation to the higher valent iron species and the hydrolytic oxide formation:

$$Fe \rightarrow Fe^{2+} + 2e^- \quad ...1$$

$$3Fe^{2+} + 2O_2 \rightarrow Fe_3O_4 \text{ and /or other oxides} \quad ...2$$

The driver of this anodic electrochemical reaction is the reduction of water-dissolved oxygen at cathodic sites to form hydroxide ion:

$$\tfrac{1}{2} O_2 + 2e^- + H_2O \rightarrow 2OH^- \quad ...3$$

Since the metal substrate can provide a convenient path to transport of electronic charge, reaction 1 and 3 often occur at separate locations on the metal surface. Typically the oxidation, reaction 1, occurs near defects; while the cathodic reaction, reaction (3), proceeds at regions adjacent to the defect. The cathodic half of the reaction, reaction (3), generates sodium hydroxide at the coating metal interface. Charge balance is maintained by sodium ion transport through the coating of lateral transport at the coating/metal interface. The alkaline cathodic corrosion product is particular detrimental to the coating - to-metal bond, and, therefore, propagates the coating failure. In addition, the generation of voluminous anodic product (the oxides have about half the density of the metal), serves to rupture the coating thereby degrading the barrier properties.

A coating will only perform its function so long as it remains intact and firmly bonded to its substrate. The Belzona 1591 satisfies this criteria for this unconventional elevated temperature application using protective coating systems.

8. CONCLUSION

The Belzona 1591 protective coating system performed exceptionally well at the elevated temperature test protocol without evidence of coating property degradation, even after occasional cyclic temperature fluctuation imposed on it. The hot quench overhead trim coolers operate at temperatures in excess of 150°C during steam operation, fashioning Belzona 1591 appropriate for this application. It is imperative that all surface preparations undertaken, comply to the Sasol SP-80-2 code.

S Nana
Senior Metallurgist

JJ Wessels
Managing Director

FIGURES

Figure 1. As-received Belzona 1591 test plate.

Figure 2. Belzona 1591 test panel after accelerated test protocol. : fully immersed

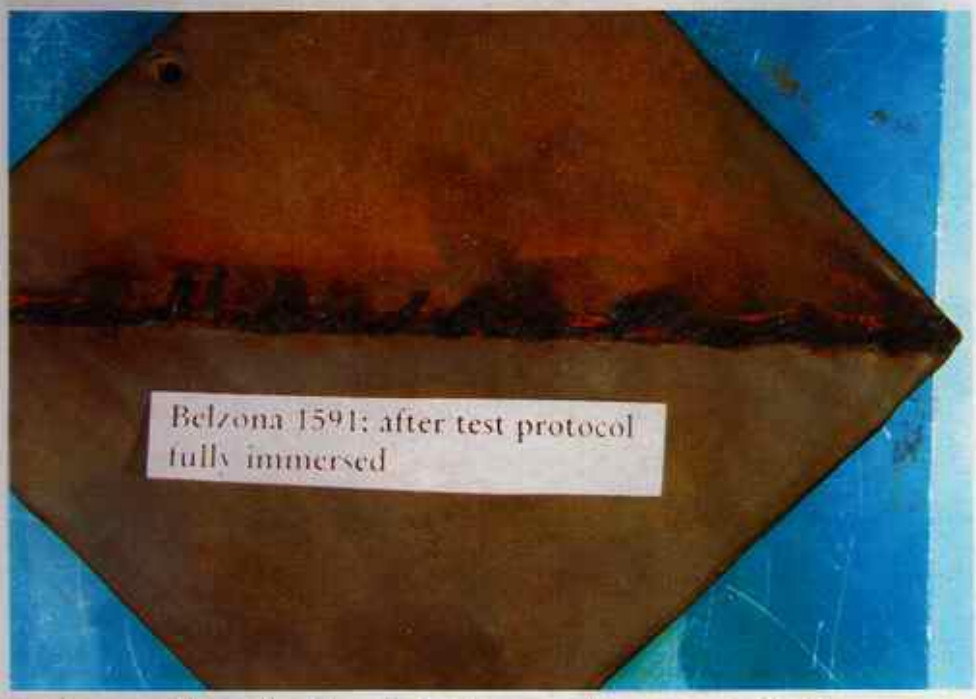

Figure 3. A close-up view of scribe : fully immersed test plate. Copious amounts of iron oxide formation at scribe.

Figure 4. Belzona 1591 test panel after accelerated test protocol. : vapor phase

Figure 5. A close-up view of scribe : Test plate in the vapor phase.

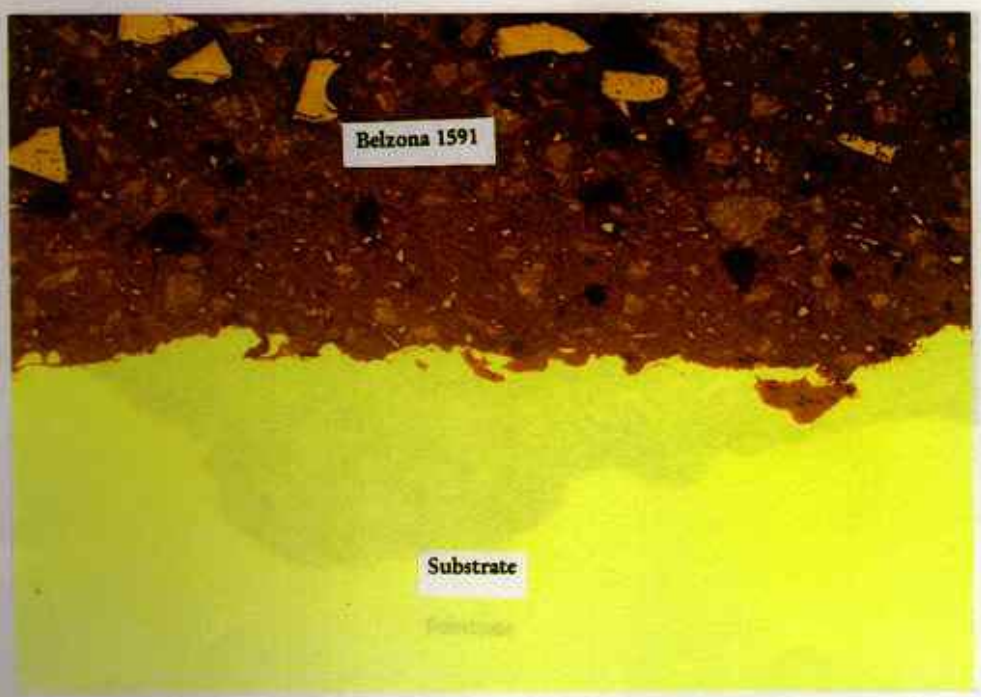

Figure 6. Micro-graph of as-received plate (bright region is carbon steel substrate) the dark region is the Belzona 1591 coating. (100X)

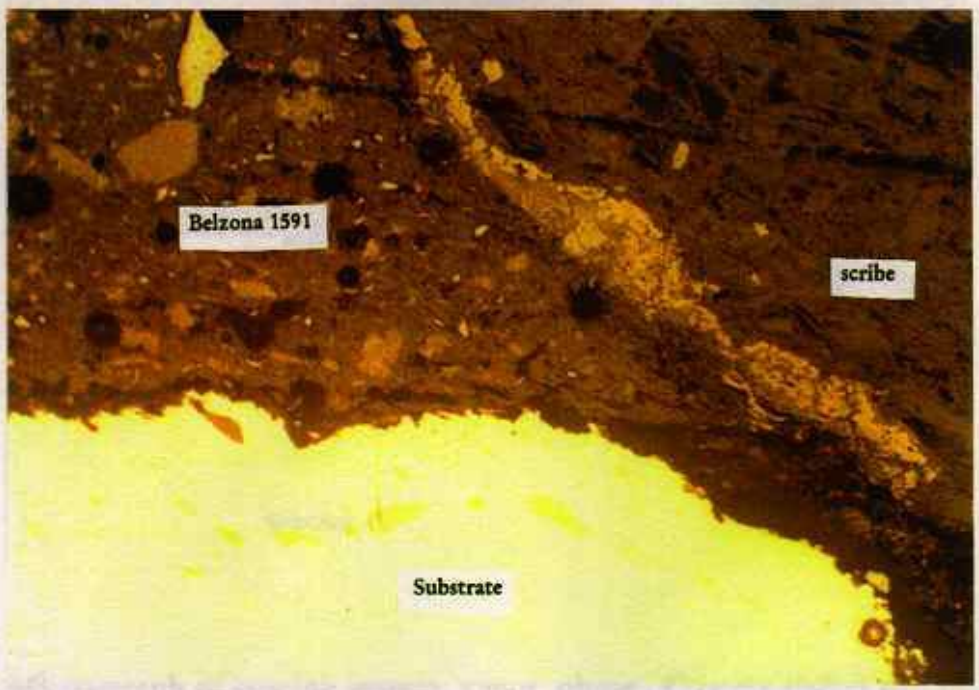

Figure 7. Micro-graph of coating system: immersed phase at the scribed region, *coating intact to substrate.* (100X).

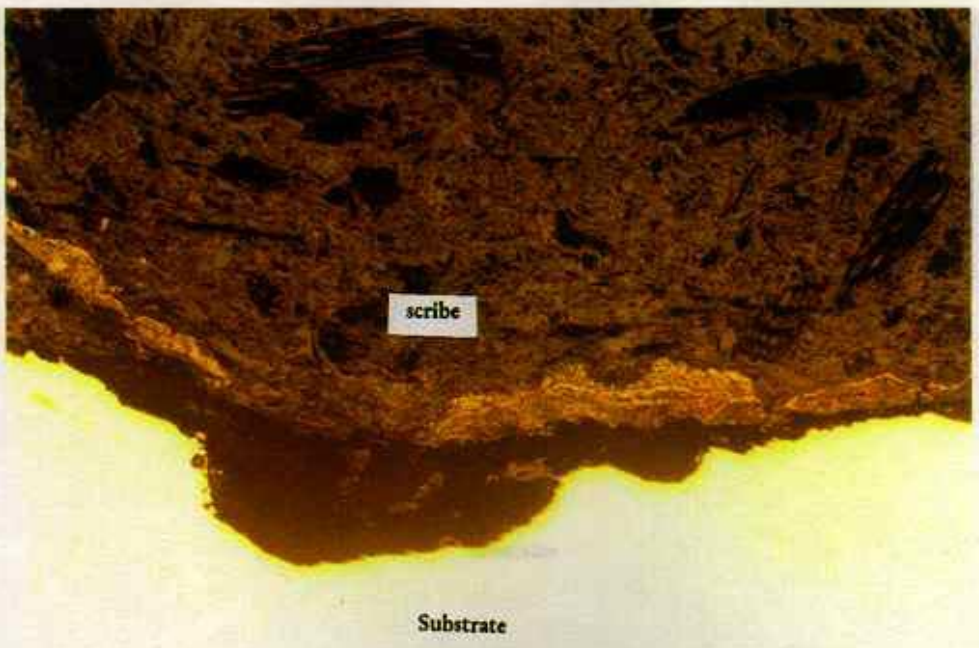

Figure 8. Micro-graph of coating system: immersed phase at scribe, corrosion attack on substrate evident immediately at scribe. (100X).

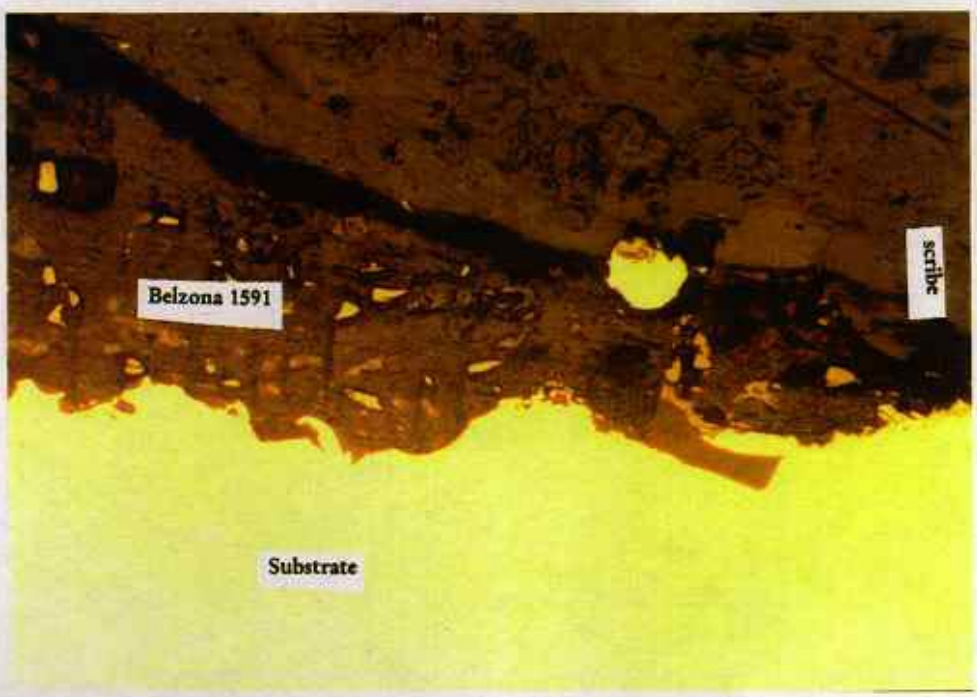

Figure 9. Micro-graph of coating system: vapor phase , *Coating system still intact after test protocol* (100X)

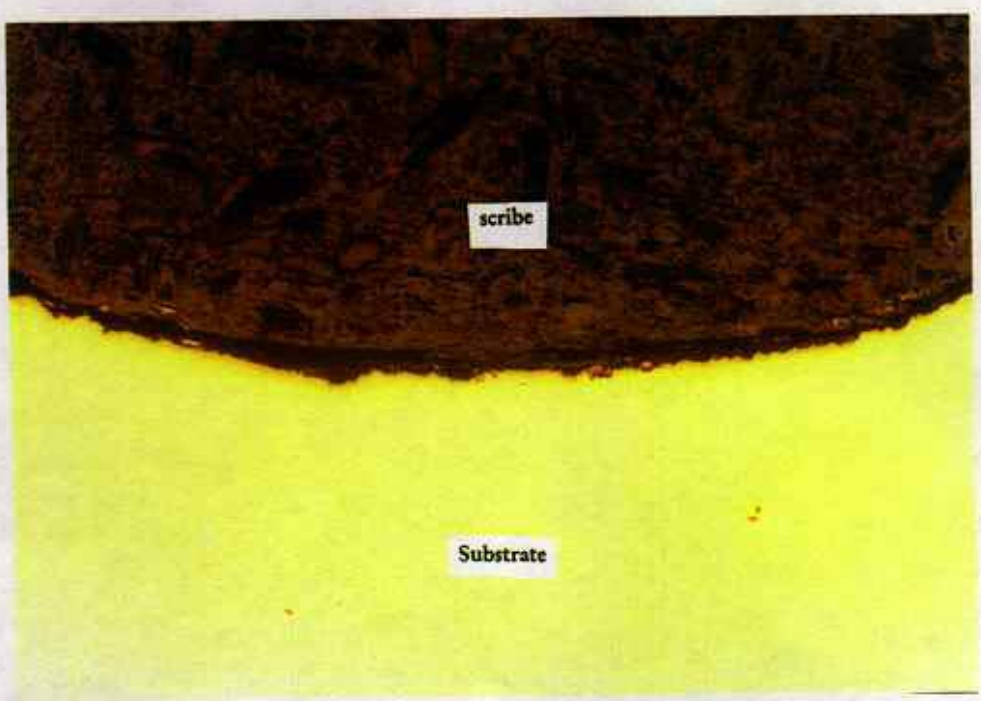

Figure 10. Micro-graph of coating system: vapor phase, immediately at scribe (100X).