In reference to Schedule "B", page 31 of 82 – Rebuild Transmission Lines – at a project cost of $4,129,000:

Q. Provide the engineering study to justify each and every project contained on page 31 of 82.

A. Except as indicated, there are no engineering studies for each of the projects in the Rebuild Transmission Lines category. A brief justification for each project follows:

Goulds to Mobile – rebuild 24L

There are presently two 66kV transmission lines that connect customers and the Company's hydro plants on the Southern Shore to the main electrical grid. The two transmission lines (17L and 24L) were built in the early 1950s and connect to the grid via the Goulds Substation. Climbing inspections on these transmission lines indicated the need for extensive upgrading, as there is significant deterioration of the poles and hardware. The deterioration of the line raises both reliability and safety concerns.

From a reliability perspective, one transmission line serving the Southern Shore is sufficient given the number of hydro plants and load in the area. Based on inspection of the transmission lines it was determined that 17L would require more upgrading. Therefore, 17L will be retired from service and the Company will focus on upgrading 24L.

Grand Beach to Salt Pond – replace conductor 301L

301L forms part of a 66 kV loop transmission system on the Burin Peninsula. The 38 km section of this line to be rebuilt was originally constructed between the late 1950s and mid 1960s. Severe corrosion of the conductor has resulted in several conductor failures in recent years and salt contamination along the coast has caused numerous outages. Without this upgrading, the performance of the line is expected to deteriorate significantly. To increase the reliability of the transmission system, 301L will be upgraded. The new line will be designed to a higher standard than the existing line in order to meet the challenge of operating in a severe environment (extreme salt contamination along the coast, high winds and severe ice accumulation). The new line will strengthen the overall Burin Peninsula transmission system.

Attachment A is a copy of an analysis of the failure of conductors on 301L, which is sought to be replaced.

Clarenville to Catalina – replace deteriorated bolts and insulators 123L

Several failures of double arming bolts have occurred on this transmission system over the years due to insufficient strength under certain loading conditions. To correct the situation, the specific locations on this line where these bolts should be replaced with the stronger double arming plates have been identified. As well inspections have identified many structures having severely worn ball link eye bolts along with older suspension insulators which have proven to be defective. The failure of either one of these components would result in the interruption of power to most customers on the Bonavista Peninsula and result in costly repairs.

Clarenville to Gambo – rebuild 124L

124L is an 80 km, 138kv transmission line that is the main link between the eastern and central sections of the electrical grid. This line was originally built in the early 1960s. Several sections have been rebuilt over the past several years mainly because of substandard ground clearances and line failures that were the result of severe weather conditions. Inspections of this line have identified a number of deteriorated structures. To correct these deficiencies, sections of this line will be rebuilt to a higher design standard, with focus in 2003 being on the sections most in need of upgrading.

Bay View to Massey Drive – rebuild 357L

The section of the line to be upgraded was originally built by Bowater Power and is of substandard construction relative to current standards. Recent inspections identified numerous deficiencies in the structures, such as deterioration in poles and cross-arms, which require upgrading in order to avoid interruptions to customers and costly repairs.

Install guy guards

Following an accident involving a snowmobile and an unmarked transmission line guy wire, the Company undertook a review of its current practice. This review recommended the installation of markers at all anchor/guy wire locations because of the potential safety and liability issues. Within the coming months, The Canadian Standards Association (CSA) will be changing its present standard to one that more clearly states that guy wires should be marked in all accessible areas. In the interests of public safety, the Company is adopting this standard immediately.

Projects < $50,000

The projects in this category mostly involve the replacement of deteriorated or defective components, such as insulators, hardware and poles, on individual transmission lines. These components have been identified during regular inspections and replacement is necessary to avoid interruptions to customers and costly repairs.

Powertech

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September 27, 2001

Project 12790-36

Newfoundland Power
P.O. Box 8910
St. John's, NF
A1B 3P6

Attention: Art Davis

Dear Mr. Davis:

RE: FAILURE ANALYSIS OF WINNIPEG AASC CONDUCTOR LINE

Powertech Labs Inc. was asked to evaluate a sample of 2/0 AASC Winnipeg conductor line (7 strands) that had failed in service and was subsequently damaged by electrical arc discharges. A sample of the failed conductor line was sent for examination along with a sample of a non-damaged section of Winnipeg conductor line. The samples were identified as 'Failed Sample' for the arc damaged failed sample and 'Non-Damaged Sample' for the sample that was undamaged.

VISUAL AND MACROSCOPIC EVALUATION

A summary of our visual observations aided by low power stereomicroscopy is as follows:

- The failed sample contained areas of melted spattered appearance, caused by arc damage (figure 1).
- Upon removal of the outside strands, the center strand of the failed section was observed to be completely covered in a white corrosion deposit (fig 2)
- The outside strands had heavy corrosion deposits on the surface of the strand that was in contact with the center strand (fig 3)
- The center strand of the non-damaged sample was also covered in white corrosion product around its entire circumference though to a lesser degree than the damaged sample.
- The outside strands had corrosion on the surfaces in contact with the center strand also to a lesser degree than the failed sample.

SEM/EDX ANALYSIS

Samples of the corrosion products noted above were removed and examined in the Scanning Electron Microscope using the EDX microprobe. The corrosion products from both samples showed high sulfur and aluminum peak as well as a minor chlorine peak. The corrosion product was also analyzed by FTIR and confirmed the presence of sulfur in the form of sulfides.

MECHANICAL PROPERTIES

Single strand tensile tests were performed on both samples of conductors. Each strand was tested individually. To facilitate the strand breaking outside the grips a fixture of liquid nitrogen was employed to cool the ends in the grips. A temperature probe was placed on the middle of the strand to ensure the center portion did not cool appreciably below ambient room temperature.

A 22" section of conductor sample was used. Failure within a gage length of 8" in the middle (4 inches from the cooled grip ends) was decided upon as criteria for a successful test.

All strands were pulled at a strain rate of 0.200"/min, on an Instron Servohydraulic test machine.

RESULTS

Table 1: Failed Sample

Strand ID	Diameter (inches)	Temp. at Center (°C)	Peak Load (lbs)	Tensile Strength (ksi)	Failure Location
Outside 1	0.149	19.4	765	43.87	Lower third of gage length
Outside 2	0.149	18.6	652	37.39	melt / spatter point in gage
Outside 3	0.149	18.8	688	39.46	melt / spatter point in gage
Outside 4	0.149	17.9	685	39.29	melt / spatter point in gage
Outside 5	0.149	20.0	658	37.74	melt / spatter point in gage
Outside 6	0.149	19.4	785	45.02	Lower third of gage length
Center	0.149	18.9	798	45.77	Middle of gage length
Average of failures at melt points			671	38.47	
Average of failures in undamaged sections			783	44.89	

Table 2: Non-Damaged Sample

Strand ID	Diameter (inches)	Temp. at Center (°C)	Peak Load (lbs)	Tensile Strength (ksi)	Failure Location
Outside 1	0.149	18.0	805	46.17	Middle of gage length
Outside 2	0.149	17.8	835	47.89	Middle of gage length
Outside 3	0.149	18.2	760	43.59	Lower third of gage length
Outside 4	0.149	19.1	825	47.31	Middle of gage length
Outside 5	0.149	18.8	812	46.57	Lower third of gage length
Outside 6	0.149	19.1	810	46.45	Lower third of gage length
Center	0.149	19.6	752	43.13	Middle of gage length
Average of outside strands			807.8	46.33	
Average of all strands			799.8	45.87	

As can be seen the average tensile strength of the good wires remaining in the failed conductor were lower than that of the average of all strands in the non-damaged sample. In the non-damaged sample the outside strands exhibited a greater tensile strength than that of the center strand.

Three full sized samples of the non-damaged sample were pulled to destruction. Liquid Nitrogen was again employed to cool the ends of the conductor being gripped to facilitate failure in the middle section. The distance between the grips was approximately 4 feet 10 inches. The results were as follows

Sample ID	Tensile Breaking Load (kN)
1	24.44
2	24.75
3	25.02
Rated strength of Winnipeg conductor	23.50

All samples of the conductor met the minimum requirement for tensile strength.

Single strand tensile tests were also performed on the outside strands from the samples of 1/0 and 4/0 conductors. The results were as follows:

Table 3: New 4/0 Sample

Strand ID	Peak Load
1	546.5
2	538.3
3	548.7
4	539.4
5	546.9
6	555.7
7	547.5
8	543.1
9	548.0
10	548.4
Average	546.3

Table 4: New 1/0 Sample

Strand ID	Peak Load
1	370.3
2	368.4
3	382.1
4	374.4
5	372.2
Average	373.5

Note: The 1/0 and 4/0 AASC conductors are compact conductors. In these conductors, the center strand is round while the outside strands are compacted into a trapezoidal shape as they are wrapped around the center. Subsequently the diameter and area measurements were not performed on these strands.

TORSIONAL DUCTILITY

Torsional ductility tests were performed on individual center and outside strands of the failed and undamaged conductor, as well as samples of the center strands from the 1/0 AASC and 4/0 AASC conductors. Testing was performed in accordance with the ASTM E558 standard. Strands were turned to failure, and the number of turns were recorded. The results were as follows:

FAILED 2/0		UNDAMAGED 2/0	
Strand ID	Turns till Failure	Strand ID	Turns till Failure
1	< 1	1	<1
2	< 1	2	1 ½
3	< 1	3	1 ¼

NEW 4/0		NEW 1/0	
Strand ID	Turns till Failure	Strand ID	Turns till Failure
1	16	1	24
2	16	2	24 ½
3	16 ½	3	25

METALLOGRAPHY

Cross sectional specimens from two outside strands and the center strand for both the damaged and undamaged samples were mounted in acrylic, and polished for metallographic examination. The aluminum wires had a fine-grained microstructure. Pitting due to corrosion was evident in all samples. Figures 4-7 are micrographs of the worst case pitting from each strand mounted. The center strand of both samples had extensive pitting around the whole cross section while the outside strands had extensive pitting in about a third of their cross sectional area, corresponding to the area that was in contact with the center strand. The strands from the failed sample had slightly worse corrosion pitting than the non-damaged sample.

MICROHARDNESS TESTS

Hardness, as the term is used in metallurgy, is a measure of the resistance of a material to indentation by an indenter of fixed geometry under a static load. Since no one combination of test load and indenter size is satisfactory for testing specimens of all sizes and all degrees of hardness, there are many hardness scales. The Vickers test, or diamond pyramid hardness test, evaluates the hardness as the ratio of the load applied to a diamond having included face angles of 136 degrees, to the surface area of the resulting impression. Hardness is a qualitative conception of a physical property of solids and can be directly correlated to the tensile strength of the material.

Microhardness tests using a Vickers diamond pyramid indenter and a 200g load were performed on the mounted Winnipeg conductor specimens. The damaged sample had an average hardness of 100 HV. The non-damaged sample had an average hardness of 96 HV

Microhardness tests were also performed on a center and outside strand from the new 1/0 conductor received. The center strand had an average hardness of 102 HV. The outside compact strand had an average hardness of 75 HV. The outside strands have a lower hardness (and subsequently a lower yield and tensile strength) than the center strand to facilitate the formation of the compact design during wrapping of the conductor.

RESISTIVITY MEASUREMENTS

Resistance measurements were taken on 12" samples of strands from both samples using a digital micro ohmmeter to ascertain the effect of the corrosion on the strands' conductivity. Following are the results obtained:

Table 5: Resistance Measurements of Sample Strands

Sample ID	Resistance (micro ohms)	Comments
Damaged (Center)	948	Probes piercing surface
	Open circuit	Probes on surface
Damaged outside	922	Probes piercing surface
	Open circuit	Probes on surface
Undamaged center	973	Probes piercing surface
	Open circuit	Probes on surface
Undamaged outside	936	Probes piercing surface
	Open circuit	Probes on surface

Open circuit measurement indicates the resistance was off scale (high).

To verify the open circuit result, a 12" sample of the new 1/0 AASC was tested with the probes on the surface. The resistance measured was 504 micro ohms, indicating the open circuit results were a result of contamination build-up.

DISCUSSION

Over a period of many years in service, the conductor wires suffered a significant amount of general corrosion. The high presence of sulfur in the form of sulfides was the main corrosion product and is common in regions near heavy industrial plants due to acid rain. Sulphur can also come from the emission of generating plants that use diesel fuel. The chlorine present can be attributed to the lines close proximity to the Atlantic Ocean. The corrosion damage was not obvious from the external appearance of the conductor, most likely because rain had washed away deposits from the outer surfaces. The corrosion loss of material in the form of pitting had reduced the cross sections of the wires to a significant extent. The loss in cross sectional area in the wires in turn affects the strength and ductility of the line and is a major concern.

The large amounts of corrosion product entrapped between the individual wires, results in high electrical resistance between adjacent wires. The high electrical resistance between adjacent wires can cause localized hotspots in the line. These hot spots decrease the tensile strength of the individual strands of the conductor and hence the overall strength of the conductor would be compromised.

CONCLUSIONS

Based on our examinations, the following conclusions can be made:

- The tensile strength of the individual strands of the failed conductor was affected by the corrosion attack. The corrosion reduced the cross section of the wires thereby reduced its strength. This caused the tensile failure of the conductor line, most likely at an acceptable service load below the rated strength. After tensile failure the line was damaged by electrical arc discharges as it fell.
- Due to the corrosion of the individual strands the overall strength of the conductor is being compromised. Although the three full size tensile samples met the minimum strength requirement, a conductor with no corrosion present would have a higher strength.
- The torsional ductility of the aluminum strands of the failed and non-damaged conductor is substantially lower than that of the new conductor, due to the loss of cross section from the corrosion attack.

- The corrosion product building of the center strands and outside strands affects the conductivity of the strands. The high resistance corrosion product essentially acts as an insulator on the surface of the strands and consequently leads to a hot spot. These hot spots decrease the tensile strength of the individual strands of the conductor and hence the overall strength of the conductor would be compromised.
- The corrosion product showed a high amount of sulfur and traces of chlorine. The high amount of sulfur in the form of sulfides was the main corrosion product and is common in regions near heavy industrial plants due to acid rain. Sulfur can also come from the emission of generating plants, which use diesel fuel. The chlorine present can be attributed to the lines close proximity to the Atlantic Ocean.

Prepared by:

Roger Trip
Materials Technologist

Reviewed by:

Avaral Rao
Senior Materials Engineer

APPENDIX ENCLOSED

APPENDIX
Figures

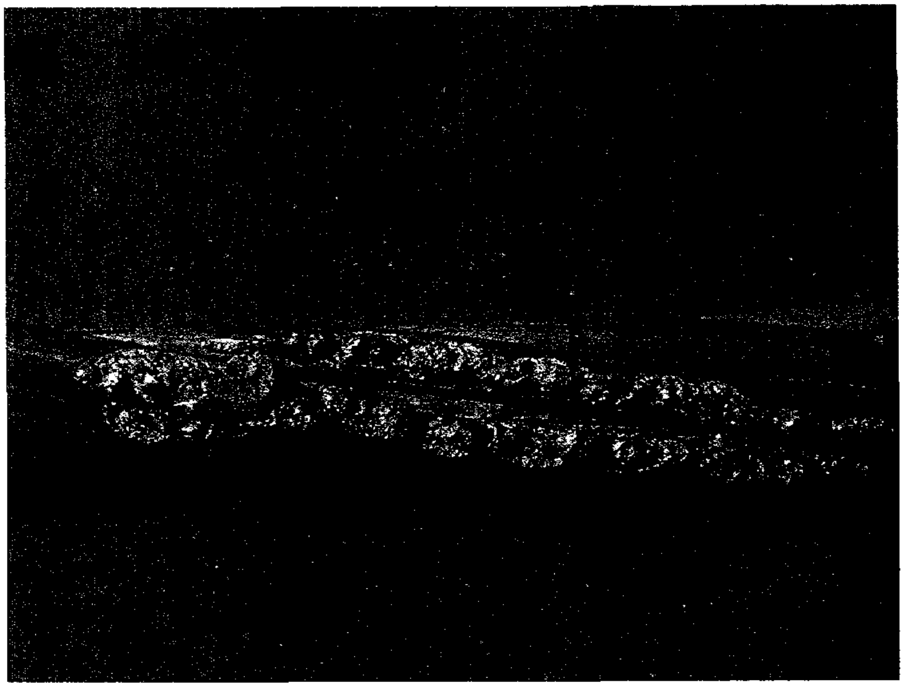

Figure 1: Arc damage on failed conductor sample

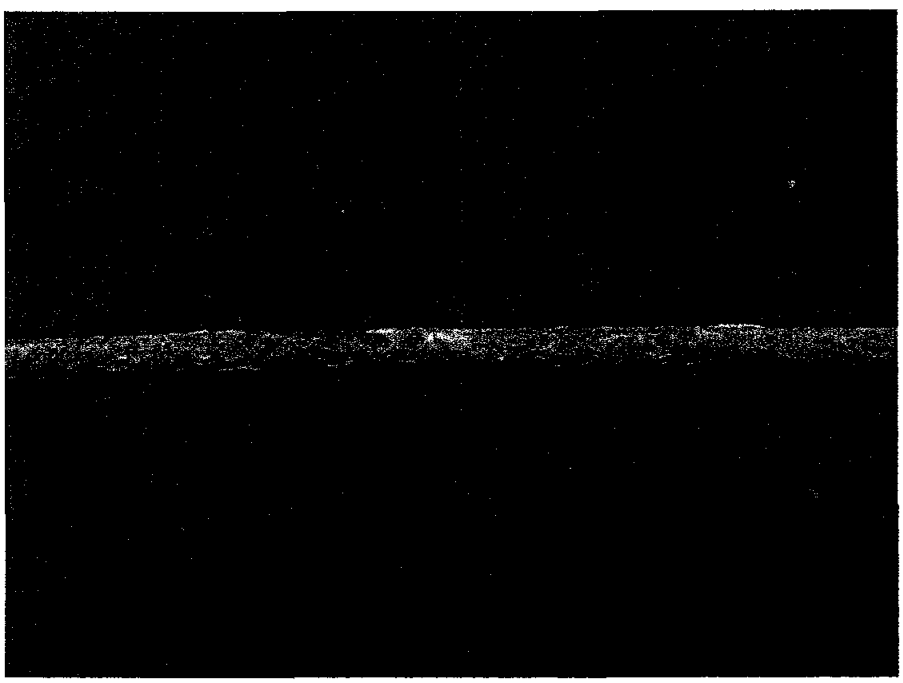

Figure 2: Center strand of failed section

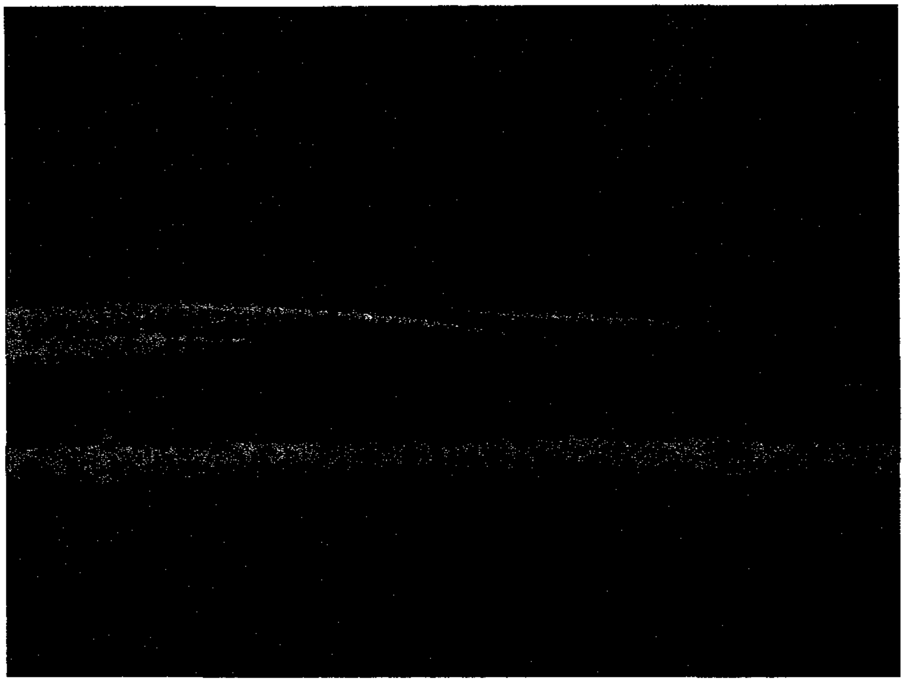

Figure 3: Outside and center strands of failed section

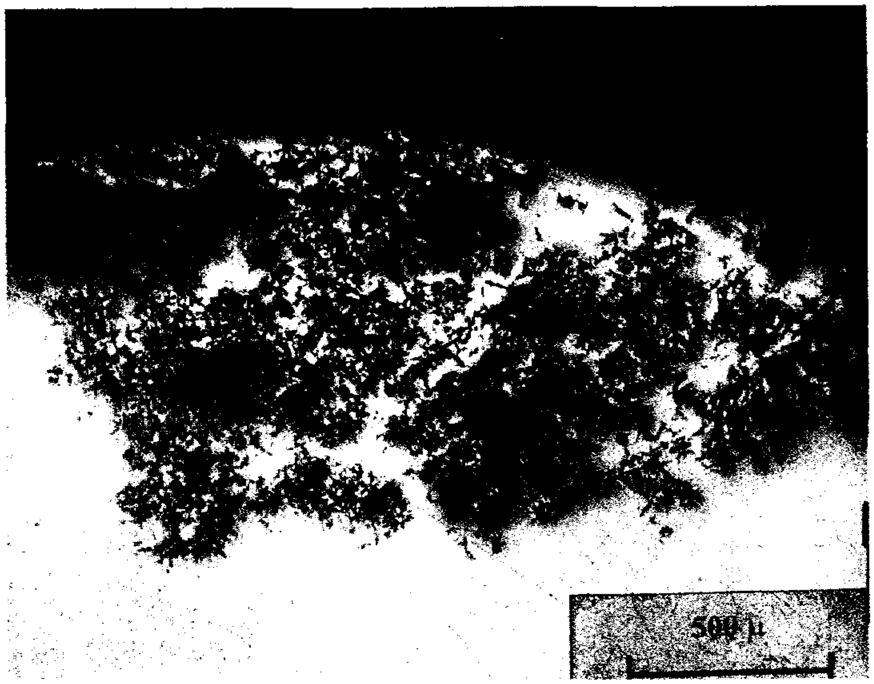

Figure 4: Worst case corrosion from center strand of failed sample

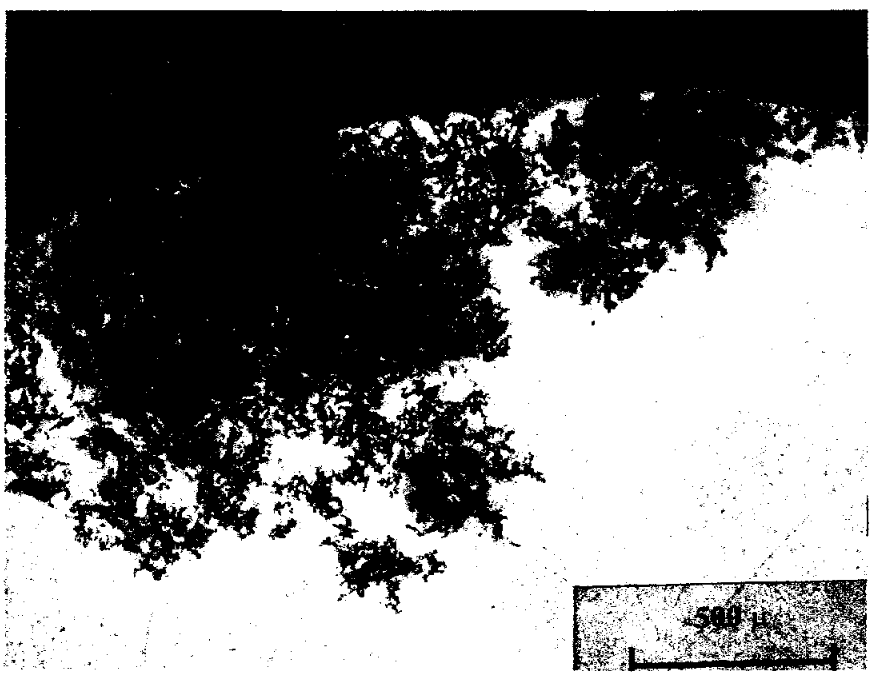

Figure 5: Worst case corrosion from center strand of non-damaged sample

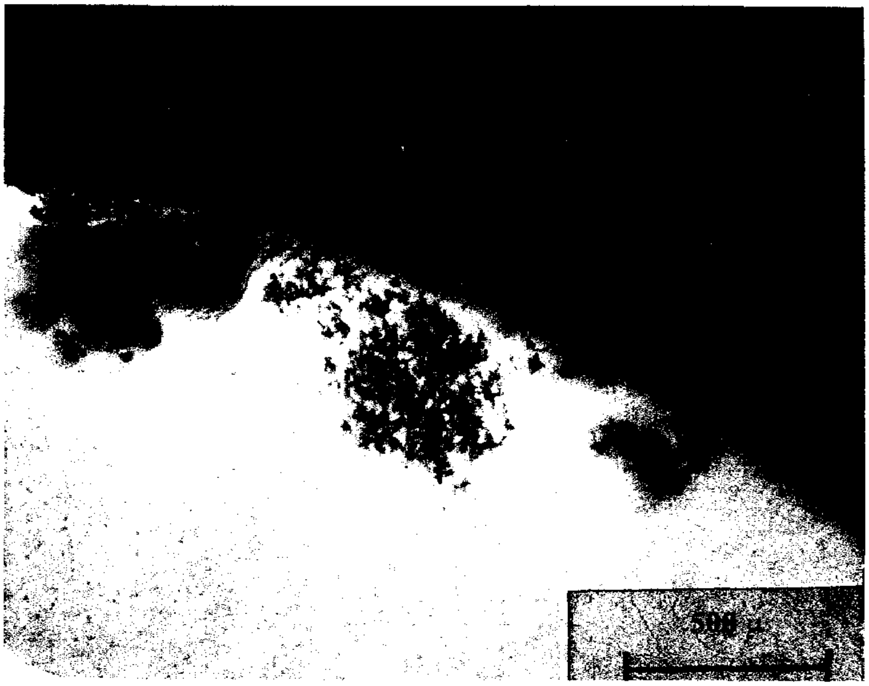

Figure 6: Worst case corrosion from outside strand of failed sample

Figure 7: Worst case corrosion from outside strand of non-damaged sample