THE RESULTS OF AN EXPOSURE PROGRAMME ON AGRICULTURAL WIRE IN SOUTH AFRICA

A.J. O'Donnell[1], R.T. WHITE [2], R.J. Bronkhorst [3], and F. le R. Fourie [4]

1. TekTrans, South African Bureau of Standards
2. International Zinc Association, Southern Africa
3. Agricultural Institute of South Africa (AEI) (retired)
4. Research & Development Division, South African Bureau of Standards

ABSTRACT

The farming industry in South Africa purchases some 240 000 tonnes of wire annually. Galvanized wire is currently supplied conforming to two specifications. However, there has been concern in the farming community (where the cost of the fence often equals the value of the land it surrounds) that the performance of galvanized wire is not predictable. In order to advise farmers on best practice in terms of installation procedures and the type of wire to purchase, a 10-year exposure program was started by the Institute of the Agricultural Research Council (ARC). This program included four types of coating over steel: light and heavy galvanizing, aluminium coating and a 95%, 5% zinc aluminium coating (Galfan). In addition, 3CR12 wire was included in the study.

This paper reports on the results of the survey over 6 sites countrywide. These sites were chosen as being representative of typical agricultural sites in South Africa. The paper discusses the relative merits of the alternative coatings together with reasons for the good performance of the galvanized wire. This information will form part of the ARC's technical literature available as guidance to farmers.

1. INTRODUCTION

The cost of fencing farmland and game ranches is considerable and can approach the land value itself, especially with respect to game fences which require high level fencing using 22 wire strands. To assist the farming community in the selection of suitable fencing wire material, the Agricultural Engineering Institute (AEI) began an atmospheric corrosion programme during 1990 on a variety of fencing wires. These included, light galvanized steel, heavy galvanized steel (both locally produced in South Africa), aluminium coated steel (imported), Galfan (95%/5% zinc/aluminium) coated steel (imported) and 3CR12 (locally produced). A total of seven sites of varying atmospheric corrosivity in South Africa were selected for this AEI atmospheric corrosion programme. These were deemed to be representative of he various agricultural climates experienced throughout South Africa (Table 1.).

TABLE 1: DETAILS OF TEST SITES.

Site	Location	Description	ISO classification
Bathurst	South East Cape	Marine influenced site	C4
Riviersonderend	Southern Cape	Inland rural site	C3
Middelburg	Eastern Cape	Inland-arid site	C2
Dundee	Kwazulu Natal	Rural/semi-industrial	C3/C4
Roodeplaat	Gauteng	Inland Industrial	C3/C4
Upington	Northern Cape	Inland-arid site	C2

Although a comprehensive five-year report for all seven sites have been published (1), occasional reference to this is only made in the paper where deemed relevant. The 11 year results reported here reflect the *in situ* performance profile and are of practical interest. This data can be used as a platform to determine longevity of the wire types by extrapolation.

For interpretation purposes of results presented in this study, it should be appreciated that a heavy galvanized coating is not of uniform thickness. Unlike a light galvanized coating that is pad-wiped (in 1990 for the locally produced light galvanized steel wire) upon being withdrawn from the molten zinc bath, thereby giving a "more" uniform coating thickness, the heavy galvanized coating is allowed to solidify (non pad-wiped) after exit from the molten zinc bath. Modern technology makes use of the nitrogen wiping technique. Specifications for hot-dip coated steel wire specify the coating in terms of g/m^2 due to the lack of coating uniformity. In the present work, coating mass (g/m^2) after eleven years is provided reflecting the average coating remaining. To address the thin coated areas and pitting effects, extensive measurements on the remaining coating thickness (coating cross-sections) have been made.

Although the exposed fencing wire samples from all six exposure sites have been collected, at the time of writing only those for Bathurst and Riviersonderend had been fully evaluated.

2. EXPERIMENTAL

The following wires were compared to initial values obtained after 11 years of atmospheric exposure.

- Light galvanized coated, nominal diameter 2,25 mm
- Heavy galvanized coated, nominal 2,23 mm
- Aluminium coated, nominal diameter 2,44 mm
- Galfan coated, nominal diameter 2,44mm
- 3CR12 wire, nominal diameter 2,48 mm

In addition, barbed samples (on oval wire, nominally 1,87 x 2,52 mm) were exposed with both light and heavy galvanized coatings.

2.1 Sample preparation for cross section measurements

The wire samples were cut between fencing posts (top wire strands). From such samples a 50 mm length was cut and respective 6 mm lengths were cut from both ends and the centre. These three cut 6 mm lengths were cold mounted in resin and prepared by standard metallographic techniques for coating evaluation on a scanning electron microscope (SEM). The remaining coating thickness was determined at magnifications ranging from 400 to 3 000 times on 32 equidistant points on the circumferential surface of each of the three samples, giving a total of 96 coating thickness measurements for the 50 mm cut sample. During coating thickness measurement cognizance was taken of the thin and thickest coated areas.

For the barbed wires, samples were taken from under the barbs (to observe the possible effects of crevice corrosion) and 2mm away from the barb (to observe any cathodic protection wastage should crevice corrosion have occurred). Analysis and observation was similar to that noted above.

The 3CR12 samples were similarly examined for pronounced pitting/stress cracking effects.

2.2 Determination of zinc coating mass

The mass of zinc coating for zinc type coatings (g/m^2) was evaluated by the stripping test method specified in South African Bureau of Standards national specification SABS 675: 1993, "Zinc-coated fencing wire (plain and barbed)". Removal of surface corrosion products prior to the mass of zinc coating determination was carried out in accordance with ASTM G1-90 "Preparing, cleaning and evaluating corrosion test specimens". The mass of coating (g/m^2) of the aluminium coating was also determined as per SABS 675 (stripping solution: inhibited hydrochloric acid) after removal of surface corrosion products by method ASTM G1-90.

2.3 Determination of tensile strength

The ultimate tensile strength (U.T.S.) and percentage elongation of the 3CR12 steel wires were determined and compared with the initial measurements prior to the 11 year exposure period at these two sites. Tensile tests were carried out to determine possible reduction in mechanical properties due to surface pitting/stress cracking effects.

3. RESULTS

3.1 Coating thickness

The remaining coating thickness and mass of coating (for coated wires) for the Bathurst and Riviersonderend sites are presented in Tables 2 and 3 respectively. In these Tables comparison is made with the respective coated wires prior to initiation of the 11 year exposure programme.

TABLE 2: BATHURST SITE COATING EVALUATION; INITIAL VS 11 YEARS EXPOSURE PERIODS

A	B		C				D	E	F
Coating Type	Coating Thickness Initial exposure (µm)		Coating thickness 11 year exposure (µm)				Mean difference (0 vs 11 years) µm (% change)	Mass of coating remaining (11 years exposure)	B – E, µm (% change)
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	B-C	g/m²	
Light galvanized	25,8	13,3	0	30	14,1	7,7	11,7 (-45%)	114,1 (16µm)	9,8 (-37%)
Heavy galvanized	51,7	20,9	5	75	23,1	6,6	28,6 (-55%)	210,3 (29,5 µm)	22,2 (-43%)
Aluminium coated	46,2	14,7	36	56	44,8	5,6	1,4 (-3%)	123,0 (45,5 µm)	0,7 (-2%)
Galfan coated	46,6*	12,1 *							

*No results after 5 years – samples lost [1]

TABLE 3: RIVIERSONDEREND SITE COATING EVALUATION; INITIAL AND AFTER 11 YEARS EXPOSURE PERIODS

A	B		C				D	E	F
Coating Type	Coating Thickness Initial exposure (µm)		Coating thickness 11 year exposure (µm)				Mean difference (0 vs 11 years) µm (% change)	Mass of coating remaining (11 years exposure)	B – E, µm (% change)
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	B-C	g/m²	
Light galvanized	12,7	6,6	3,3	11,25	7,5	2,0	5,2 (-41%)	61 (8,7 µm)	4 (-32%)
Heavy galvanized	53,1	19,4	24	80	47,7	15,3	5,4 (-10%)	350 (49,1 µm)	4 (-7,5%)
Aluminium coated	45,5	13,5	32	70	44,7	7,9	0,8 (-2%)	125 (46,3 µm)	*
Galfan coated	45,2	14,4	30	90	49,4	13,8	*	307,8 (43,9 µm)	1,3 (-3%)

* Thickness gain

The initial control sample wires used for the experiment were measured. These values are based on the mass of coating by stripping test method and the following coating thickness values were recorded for Bathurst as well as Riviersonderend:

- Lightly galvanized : 20 µm ;
- Fully galvanized : 51 µm;
- Aluminium coated : 44 µm ;
- 95%/5% zinc/aluminium coated : 44 µm.

An exception was made at Riviersonderend as a lightly galvanized coated oval wire was used, and measured (2) to be 9,5 µm.

The marked reduction in standard deviation values for 11 years results in Tables 2 and 3 are attributed to the far greater number of thickness measurements made (92 as against 18 for the initial results (1). However, in addition, the greater standard deviations obtained from the heavy galvanized samples reflects the initial localized attack during corrosion of the outer zinc layer.

With respect to the other four sites, visual observations showed that all the samples from both Middelburg and Upington (both classified as C2 environments) sites showed minimal corrosion. In contrast, the samples from Dundee and Roodeplaat (both classified as C3/4 environments) exhibited pronounced darkening of the coating surfaces. Both sites are near to industrial zones.

3.2 Mechanical properties

The mechanical properties of the 3CR12 wires for both sites are presented in Tables 4 (Bathurst) and 5 (Riviersonderend) respectively. The mechanical properties of the 3CR12 wires prior to the 11 year exposure duration are also included in Tables 4 and 5 for comparison purposes.

TABLE 4: BATHURST SITE - MECHANICAL PROPERTIES OF 3CR12 WIRE, INITIAL AND AFTER 11 YEARS EXPOSURE PERIODS

EXPOSURE PERIOD	U.T.S., MPa (% change 11years/initial)	% ELONGATION (% change 11years/initial)
Initial	912	7,3
11 Years	685 (-25%)	5,0 (-32%)

TABLE 5: RIVIERSONDEREND - MECHANICAL PROPERTIES OF 3CR12 WIRE, INITIAL AND AFTER 11 YEARS EXPOSURE PERIODS

EXPOSURE PERIOD	U.T.S., MPa (% change 11years/initial)	% ELONGATION (% change 11years/initial)
Initial	938	8,1
11 Years	816,2 (-13%)	7,7 (-5%)

3.3 Cross-sectional coating SEM views of samples after 11 years exposure

Selected cross-sectional coating views after the 11 year exposure duration at both sites are presented in Figs. 1-10. These plates illustrate corrosion effects i.e. presence of surface corrosion products (accompanied by reduction in coating thickness), lack of such effects and coating uniformity.

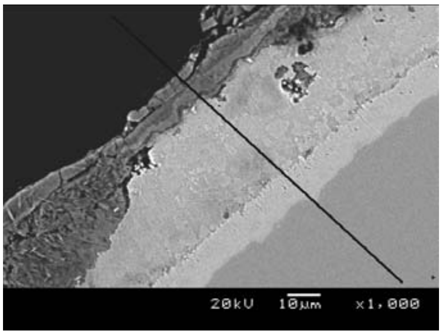

Fig 1: Heavy Galvanized-Bathurst

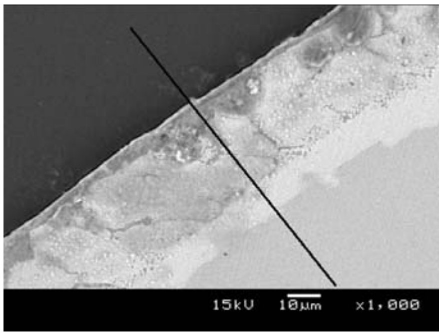

Fig 2: Heavy Galvanized-Riviersonderend

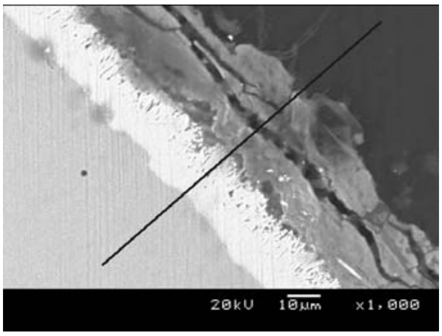

Fig 3: Light Galvanized-Bathurst

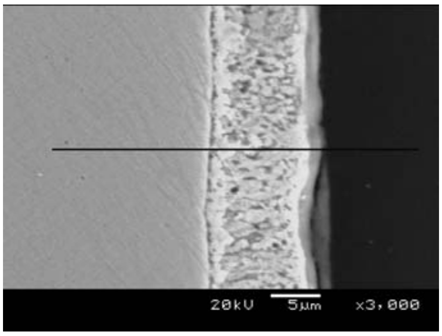

Fig 4: Light Galvanized-Riviersonderend

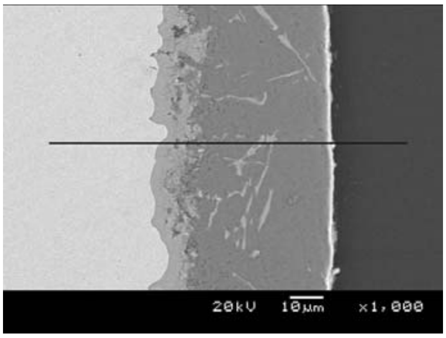

Fig 5: Aluminium Coated-Bathurst

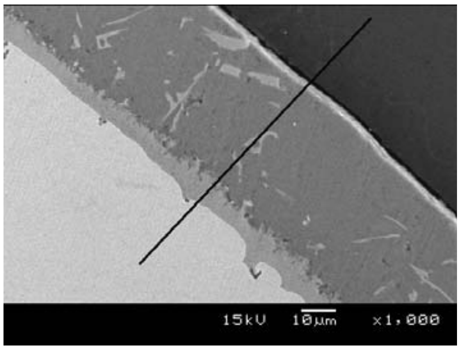

Fig 6: Aluminium Coated-Riviersonderend

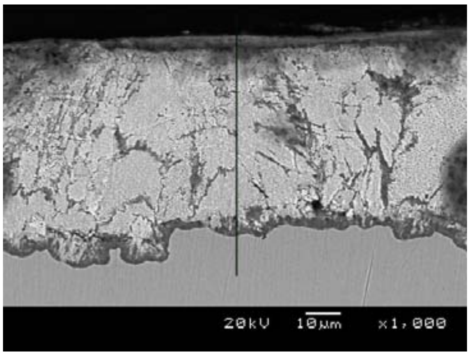

Fig 7:Galfan Coated-Riviersonderend

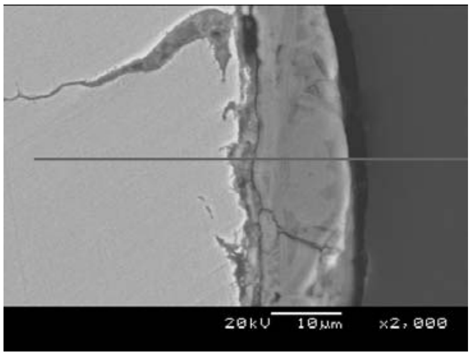

Fig 8: 3CR12 - Bathurst

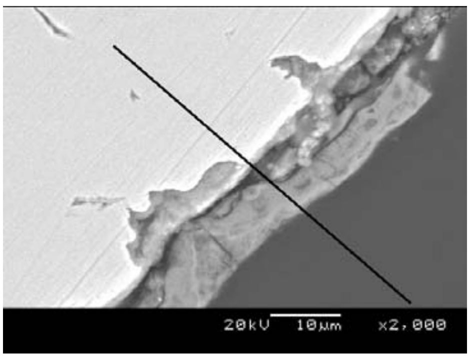

Fig 9: 3CR12 - Bathurst

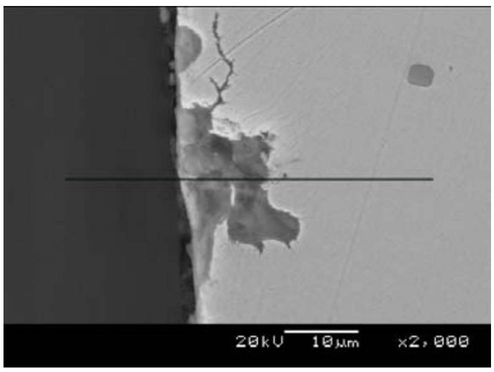

Fig 10: 3CR12 - Riviersonderend

4. DISCUSSION

4.1 Bathurst site

The results obtained clearly demonstrate Bathurst, which is a marine influenced site, to be the significantly more aggressive site. The reduced coating loss (SEM) for the light galvanized coating of 11,7 µm represents a 45% decrease in coating compared to the original sample. The heavy galvanized coating lost 28,6 µm (55%) over this period. For the light galvanized coating, this loss is attributed to the fact that much of the coating has now corroded to the iron / zinc alloy layer that is more corrosion resistant than the outer pure zinc layer of the coating [(3)]. The overall life expectancy of heavy and lightly galvanized is similar. However, for the lightly galvanized wire, minimum values of zero for the coating have been recorded thereby initiating the onset of sacrificial protection by the zinc of such exposed areas. Therefore, the thinner light galvanized coating is unlikely to provide another 11 years effective protection.

The term “sacrificial” is aptly named as although the surrounding zinc will galvanically protect exposed steel, it does so at an enhanced rate i.e. over and above that of its normal corrosion rate for a given environment.

The 11 year heavy galvanized coating sample, with a mean coating thickness (SEM) of 23,1 µm remaining, will probably last another 8 years based on the work of Callaghan [(4)]. However, some enhanced corrosion of the coating may occur (sacrificial protection by zinc) due to low minimum point coating values being evident after the 11 years exposure duration.

The Aluminium coating showed little loss (3%) due to corrosion and should last further for many decades.

The Galfan coating, after 5 years exposure, (not given in Table 2) showed a coating loss of almost 14 µm compared to the original. It should be noted that previous evaluations were carried out by different authors from those for this paper. This would therefore give a corresponding Galfan corrosion rate of almost 31 µm if extrapolated to 11 years. This is greater than the 28,6 µm mean loss for the heavy galvanized coating. Such a Galfan coating loss is certainly debatable as it is known that Galfan is much more corrosion resistant than a galvanized coating, at least twice for a sodium chloride salt environment [(5)]. It is also relevant to note that, as shown in Table 2 for the relatively rural Riviersonderend site, Galfan corroded little if at all compared to values in excess of 5 µm for a galvanized coating. Based on ISO 9223 [(6)], the Bathurst site can be classed as a C4 site for corrosion of zinc.

4.2 Riviersonderend site

The results shown in Table 2 demonstrate a low zinc corrosion rate. These values agree well with the long-term 20-year atmospheric corrosion programme in South Africa by Callaghan. At this site the heavy galvanized coating will give many decades of future effective life (in excess of 40 years). The lightly galvanized coating will probably last another 10 years at least.

At this site the exposed Aluminium (2% reduction) and Galfan coatings demonstrated extremely minimal corrosion rates and could well “go on for ever at this rural site”. Based on ISO 9223, the Riviersonderend site can be classified as a C2 site for corrosion of zinc.
Note - The marked reduction in standard deviation values for 11 years results in Tables 1 and 2 are attributed to the far greater number of thickness measurements made (92 as against 18 for the initial results).

4.3 3CR12

The mechanical properties of 3CR12 after 11 years exposure do show a significant reduction in U.T.S. and also a reduction in the percentage elongation compared to those prior to the 11 years exposure. The reduction in U.T.S. (25%) and percentage elongation (32%) at the Bathurst site was greater than that at the Riviersonderend site where the UTS reduced by 13% and the % elongation by 5%. This could be attributed to surface pitting and stress cracks that are more pronounced for the aggressive Bathurst site as shown in Figs 8 and 9. (It should be noted that erect fencing wire is under stress, approximately 100 MPa).

5. CONCLUSIONS

1. Light galvanized coatings will not give adequate life at marine influenced sites (C4), heavy galvanized coatings will be preferred. It is however, doubtful if even the heavy galvanized coatings would give full effective protection for 20 years.
2. For a rural (non polluted) area (C2) a light galvanized coating will probably last effectively for about 20 years. Heavy galvanized coatings for such a site should last significantly longer.
3. Both Galfan and Aluminium by far gave the optimum performance at all sites with little if any, corrosion of the coating being observed.
4. The long term use of the rust resisting steel is less favourable as the wire is subject to pitting and stress cracking, especially in marine environments, which enhances deterioration in tensile strength.

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REFERENCES

1. R.J. Bronkhorst, Corrosion of Fencing Wires. Institute for Agricultural Engineering (South Africa) 1997.
2. K.L. Rodseth, Initial Report on the Exposure of Fencing wire at selected sites in South Africa. CSIR (South Africa), p.4 – 9 (1991).
3. A.J. O’Donnell, Corrosion Resistance of iron/zinc alloy layers, (unpublished). South African Bureau of Standards.
4. B.G. Callaghan, Results of a Twenty Year National Exposure Programme (Atmospheric Corrosion Testing in Southern Africa), CSIR (South Africa), p. 49 (1990).

5. A.J. O'Donnell, An Evaluation of the Sacrificial Protection Afforded by Continuous Galvanized Coatings, Ph. D. Thesis, University of Pretoria, pp 4.1 – 4.60 (1990).
6. International Standards Association, Corrosion of metals and alloys – Corrosivity of atmospheres – Classification ISO 9223 (1992).