A guide to the performance of hot dip galvanized piping in water.

RT White[1], JT Pressly[2] and AJ O'Donnell[3]

1. Project Manager, South African Zinc Initiative
2. Formerly Head of Section, Anglo American Research Laboratories
3. Subject Specialist, South African Bureau of Standards.

Abstract

Hot dip galvanizing has been used for the transport of water for many years. As a result, a large quantity of data exists on its performance. Many of the early recommendations for use were based upon intuition and case-by-case experimental testing. Where failures occurred, these were documented and, over a period of some 20 years, have resulted in changes in tube making practices and the galvanizing requirements for tubing in particular. This paper documents these changes and highlights the attempts made by various interested parties, manufacturers, specifiers and users to change the product to allow for more confident use of galvanized piping for the transport of water. The use of the Scanning Reference Electrode to provide guidance on weld performance is highlighted together with the large volume of study to show how practical changes could improve performance.

Once, these changes were implemented, it was necessary to produce a guide on the application criteria to be measured to provide guidance for the use of galvanized piping. This has culminated in South Africa in the provision of a Code of Practice through the South African Bureau of Standards.

Keywords – galvanizing, water, piping

Introduction

Historically, steel was the preferred material for the conveyance of water. However, steel has to be coated and/or lined to provide for long-term performance. For service and plumbing systems (< 200mm diameter) early piping was seamless with galvanizing normally applied to ~ 75 µm in thickness). Since the 1960s a move was made away from seamless to autogenously electric resistance welded (ERW) pipe. The ERW process is cheaper than the seamless process and allows the production of thinner walled product with superior dimensional tolerances [1]. The high frequency ERW process produces a narrow Heat Affected Zone (HAZ); results in hot working of material adjacent to the weld and can provide for grain refinement. These factors result in a weld with good mechanical properties.

Notwithstanding these advantages, a number of failures of ERW galvanized water piping occurred in the 1970's in South Africa, in areas where the seamless product had given satisfactory service (~ 25 years). As a result of the pipe failures, a major study was initiated by the National Building Research Institute [2]. The major conclusions of this study were:

1. The weld area tended to be significantly anodic to the adjacent metal and,
2. The galvanizing quality was variable often providing insufficient protection.

A series of studies have been carried out over the years to highlight the major causal factors in affecting weld-line corrosion and the galvanizing requirement to maximize the performance of galvanized piping. These may be divided into two types of studies. The first have focused upon the requirements of the weld area itself, the second have resulted in the development of the new EN standard. Both activities are briefly described to provide a background to this study.

Studies in the 1980s showed that, the freer the steel from inclusions, the less anodic the weld to the adjacent material. Tests looking at a range of steels by the Council for Scientific and Industrial Research (CSIR) in South Africa, using the Scanning Reference Electrode Technique (SRET) showed that steels with higher sulphur content exhibited a high potential profile across the weld (Fig. 1) [3]. Other studies indicated that for practical purposes a sulphur level of 0.02% produced acceptable performance in a more realistic environment [4].

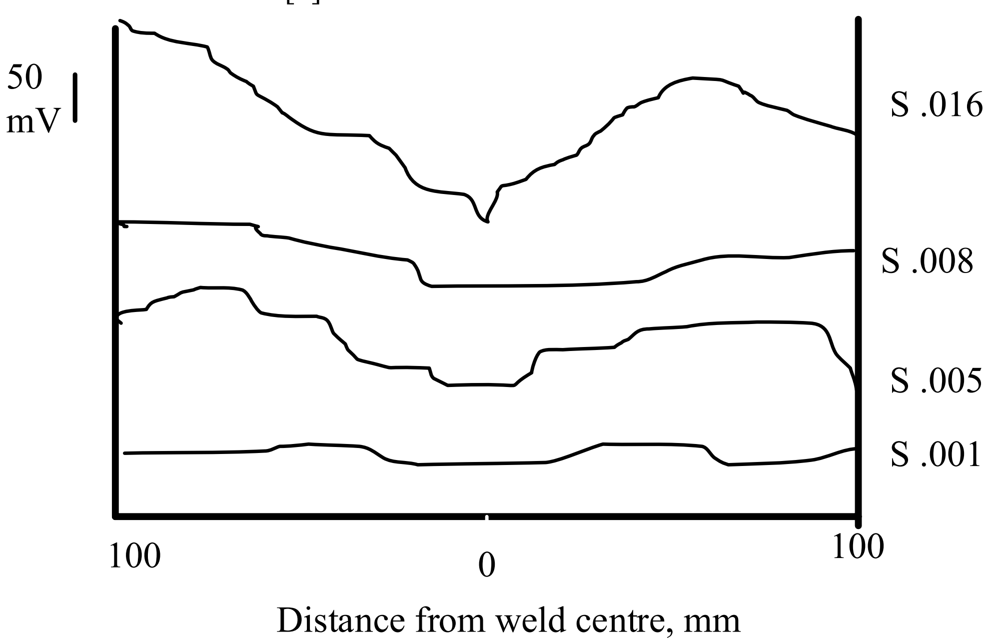

Figure 1. SRET profiles for a number of steels after HF welding with different percentage sulphur levels [3].

The South African Standard, SABS 62, contained no requirement for the maximum sulphur content for steel used in the tube making process [5].

The CSIR studies also indicated that fissures in the galvanizing resulting from a poor weld profile could prejudice the corrosion performance in the vicinity of the weld. However, other studies indicated that the influence of tube quality arises from the structure of the zinc coating in addition to the property of the weld seam [6]. When the coating consists entirely of zinc-iron alloy phases (which may occur when the tube cleaning steam pressure is too high and blows off all the outer eta alloy layer) the conductivity of the oxide layer is very high from the onset and corrosion cells form easily.

Developments in galvanizing specifications over the years hint at the necessity to police the quality of the coating in terms of thickness, integrity and adhesion. Surface variability and coating quality have been the main concerns [6,7]. In South Africa, it became clear that the SABS 763 specification was rather incomplete and inadequate. The standard thickness of 45 µm could result in inadequate coverage of the weld area in particular. In addition, if the height of the weld burr was too great, the performance of the total system would be compromised as a result of the potential reversal over the weld. It became clear that the SABS Standards needed revision. In 2000, the SABS 763 standard was replaced by the EN 10240 [8].

Revision of the SABS 62 standard to incorporate maximum requirements on sulphur levels and require internal weld bead height control was completed in 2002 [9].

Numerous studies on the performance of piping systems for the conveyance of potable water have been carried out in South Africa [10,11,12]. It became clear from these studies that a method of predicting piping performance was required for use by authorities, specifiers and users.

Experimental

The development of the DIN 50 930 specification provided an opportunity to look at the possibility of developing a local guide for the use of piping for the transportation of potable water. Part 3 refers specifically to galvanized piping and presents an assessment criteria approach to its performance. Developed in 1980 with the last revision being in 1993, this standard was developed in order to provide comprehensive guidance on the performance likelihood for galvanized material in contact with water [13]. This document has been subject of peer review [14]. In South Africa, a model for the requirements of water quality to ensure transportation of potable water without scaling has been produced [15].

A group of experts was detailed to determine the best approach to use to provide a guide for the use of galvanized piping in potable waters. Using the information available from various sources, including that referenced above, a Delphi approach was used to devise a simple global assessment criterion to be applied to a particular water quality to determine its suitability with reference to galvanized piping. This was done using the assumption that the piping would comply with the requirements of the revised SABS 62 and that the galvanized coating would comply with the EN 10240. Tables 1 and 2 indicate the compliance requirements for the pipe system and the parameters determined as important by Delphi analysis.

Table 1. The properties required of the galvanized piping system.

Component	Property met	Comments
Steel	S < 0.02%	Requirement to minimize weld attack
Tube	Weld bead height controlled	Requirement to provide smooth profile, no high points and no crevices
Galvanizing	Complies with EN 10240	Coating thickness such that some eta layer present

Table 2. Water quality parameters determined as important

Parameter	Range	Comments
Flow rate	Flowing/standing/ anaerobic	It is considered that flowing water will stabilize the protective hydrozincite film on the zinc surface.
$Qs = \frac{[Cl^-] + ½[SO_4^{2-}]}{Ks\ 4.3}$ [1]	0 to 5	This represents the ratio of aggressive to scaling ions. When the value is less than 1, a scale produced is unlikely to be re-dissolved.
Ks 4.3 [2]	0 to > 300	The presence of reserve alkalinity assists in the formation of the protective hydrozincite scale.
Calcium hardness, mg/l	0 to > 80	The presence of calcium hardness assists in the promotion of protective scales
Calcium carbonate precipitation potential (CCPP)	0 to >6	Ideally water should form an eggshell scale. Highly scaling water is undesirable as is non-scaling water. Traditional indices give no information on the kinetics of scale formation.
pH	5.5 to >7	The galvanizing coating has been shown to be resistant in the range 5.5 to 12. Beyond these limits, soluble zinc salts are produced.

1. All concentrations in milli-equivalents per litre.
2. Ks 4.3 is the total alkalinity of a water (mg/l as Ca CO_3)

Using the above guidelines, a series of historic analyses were carried out on various systems where the water quality parameters were known. In all cases, data used was taken from third party laboratory assessments.

Results

A number of test cases were used for determination of the probability model. These are listed in Table 3. Analyses of the various waters being transported by the galvanized piping are shown in Table 4. In all cases, the performance of galvanized piping has been determined.

Table 3. Test case descriptions

Sample Identification	Sample location	Comments
1	Borehole water	Borehole tubes installed with no general corrosion
2	Doorndraai Dam water	Test report suggested water unsuitable for galvanized piping
3	CSIR, Pretoria	Corrosion rate determined as 1.5 µm/yr
4	Vaal Dam water	Corrosion determined as 2 µm/yr
5	Klerksdorp	Corrosion determined as 1.5µm/yr
6	Vereeniging	Corrosion determined as 1.6µm/yr
7	CSIR, Pretoria	White uniform scaling after 42 months
8	Mine water, Platinum mine	Water borderline
9	Groblersdal Water main	Tests indicated water suitable for galvanized piping
10	Mine service water	Galvanized piping failed
11	Mine service water	Galvanized piping failed
12	Doorndraai water	Tests indicated water suitable for galvanized piping.

Table 4. Analyses and flow rates of galvanized piping in various locations in South Africa.

Sample	1	2	3*	4*	5*	6*	7	8	9	10	11	12
Flow rate	High	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low
pH	6.95	7.5	7.69	7.84	7.88	7.91	7.8	6.5	7.72	5.85	6.34	7.8
Chloride, mg/l	70	4.5	20.4	12	88	18	15	10600	18	3500	1920	20
Sulphate, mg/l	20	1.3	34.6	15	147	39	32	945	96.6	499	148	3
Ks 4.3	107	34	95	71	121	86	88	35100	60	30	30	50
Ca , mg/l	32	5.7	28.7	37	57	33	27	5690	26.6	2085	1010	8.8
TDS, mg/l	265	66.8	228	138	690	221	187	14780	252	7867	3384	120
Cond, mS/m	37	9	33	20	100	32	34.4	1970	40.2	670	420	17.4
Qs	1.1	0.2	0.7	0.5	2.3	0.8	0.6	0.5	2.1	182	95	0.6
CCPP	-34	-7.7	-3.2	-0.6	5.1	0.2	-2.1	14074	-3.9	-56	-26	-5.3

*average values

Discussion

The corrosion of zinc towards the stable production of hydrozincite proceeds by:

Anodic reaction $Zn(s) \rightarrow Zn^{2+} + 2e^-$ ……………………………………..(1)

Cathodic reaction $\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2\,(OH^-)$ ……………………………(2)

Hydrozincite precipitation: $5Zn^{2+} + 2HCO_3^- + 8OH^- \rightarrow Zn_5(OH)_6(CO_3)_2\,(s) + 2H_2O$ .. (3)

Dynamic equilibrium: $Zn_5(OH)_6(CO_3)_2\,(s) + 8CO_2 + 2H_2O \leftrightarrow 5\,Zn^{2+} + 10HCO_3^-$ …(4)

Clearly, oxygenated water is required to facilitate the production of soluble zinc ions, which are then precipitated by the presence of reserve alkalinity. The protective precipitate is held in dynamic equilibrium by the presence of carbon dioxide. Too high a level of carbon dioxide results in breakdown of the precipitate, too low a level can result in accelerated zinc corrosion. Thus a balance is required. This dynamic process illustrates the intuitive reasoning behind the identification of the water quality determinants.

Reference to global systems included in the DIN standards indicates that a simple additive method of the identified parameters is a recognized approach. Table 5 gives the tabulated values used in evaluating the probability of performance for galvanized steel for the samples listed in Table 4 with reference to table 6 of DIN 50 929, Part 3 [16].

Table 5. Probability performance for galvanized steel in contact with water

Value	Parameter	Unit	Rating DIN	From studies
A	**Water condition**			
	Flowing		-2	2
	Standing		+1	1
	Anaerobic		-5	-5
B	**Qs**			
	Less than 1			0
	1 to 2			-1
	2 to 5			-2
	Greater than 5			-3
C	**Ks 4.3**	mg/l (Ca CO_3)		
	Less than 50		-1	-1
	51 to 200		1	1
	201 to 300		1	0
	Greater than 301		0	-1
D	**Calcium Hardness**	mg/l		
	Less than 20		0	-1
	20 to 80		2	2
	Greater than >81		3	3
E	**pH**			
	Less than 5.5		-6	-6
	5.5 to less than 6.5		-4	-4
	6.5 to 7		-1	-1
	Greater than 7		1	1
F	**CCPP**			
	Less than 2			1
	2 to 4			-1
	Between 4 and 5			0
	Greater than 5			2

The probability of performance is given by simple addition, i.e.

Overall probability of performance P = ∑ (A-F)
Where P greater than 1 = satisfactory
P less than 1, but greater than -3 = fair
P less than -3 = unsatisfactory

The performance of this modified model is shown below in Table 6.

Table 6. Probability of performance using the proposed model.

Value\Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
A	2	2	2	2	2	2	1	2	1	1	1	1
B	-1	0	0	0	-2	0	0	0	-2	-3	-3	0
C	1	-1	1	1	1	1	1	-1	1	-1	-1	-1
D	3	2	3	2	3	3	3	3	2	3	3	-1
E	-1	1	-1	1	1	1	1	-1	1	-4	-4	1
F	1	1	1	1	0	1	1	2	1	1	1	1
P	5	5	6	7	5	8	7	5	4	-3	-3	1
Test confirms	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

From this, it becomes clear that the model is applicable for potable waters. As a result of this, a Code of Practice has been devised in conjunction with the South African Bureau of Standards [17]. An introduction outlines the rationale behind the code, which, in turn, will be modified and developed as its use increases.

Conclusions

1. A review of existing data provided guidance for the development of a model to predict the performance of galvanized piping for the transportation of potable water.
2. The model has been checked against a series of known systems and has been modified to provide reliable prediction data.
3. A Code of Practice has been produced from the developed model.

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