Mild Steel Pipeline Weld Corrosion

Welding is widely recognized as a powerful and reliable technique for the construction industry and for infrastructure. Most structures involve the use of mild and low alloy steels and they can be found in many heavy industrial applications including pipelines. However, when exposed to the marine environments mild and low alloy steels are prone to corrosion, mainly in the form of pitting attack, and usually this is particularly severe in the Heat Affected Zone of welds. This may influence the long-term safety and reliability of welded structures in marine environments. Unfortunately corrosion can occur even with the use of modern prevention and mitigation techniques such as protective coatings and cathodic protection, particularly if these are not well-maintained or where they are not feasible.

Estimates on the cost of corrosion worldwide are in excess of AU$2.2 trillion a year (including AU$13 billion in Australia and AU$246 billion in the USA). These costs include replacement or rehabilitation of facilities and equipment and ultimately are passed on to the consumer, either directly or through increased in utility and service charges.

For engineers the potential for structural failure is always of major concern. For this reason there is a strong interest in the rate of corrosion, and in particular for pipelines, the rate of pitting corrosion. Some typical recent results are shown in the Figure (Chaves and Melchers 2011). It shows the growth in pit depth as a function of exposure time as measured on welded mild steel coupons tested under immersion seawater conditions. The black and red lines represent the pit depths for different parts of the weld. The green trend represents what is still the traditional approach for representing the depth of pitting, it has been used for more than half a century.

The Figure shows the green line as the so-called power law, which consists of a bi-logarithmic model c(t)=A·t, where A and B are constants obtained empirically (Melchers 2005a). Its prediction can be quite conservative at the early stages of pitting but it is quite unconservative (optimistic) for longer term exposures and this should be of concern for infrastructure applications. The reason for the poor long-term prediction is that much corrosion research is focused on the risk of corrosion initiation and also with relatively short-term pit depth progression, typically measured in terms of hours, days or sometimes weeks. In contrast, structural engineers tend to be more concerned with the progression of corrosion with long periods of time (years, decades) and therefore with the rate of longer-term structural deterioration once corrosion has commenced. However, long term data is scarce, and anecdotal reports in the literature and corrosion handbooks (Southwell et al. 1986, Blekenhorst et al. 1986, Smialowska 1986 and Melchers 2005b).

For both rational economic decision-making and for structural engineering assessments there is an increasingly need to estimate the likely progression of infrastructure deterioration with time. Structural reliability theory provides a sound framework for this. Unfortunately, currently available models for corrosion consider the parameters which may affect pitting corrosion and hence the reliability of pipelines, to be deterministic variables rather than as random variables. Statistically speaking, an engineering random phenomenon is associated with possible outcomes. Such outcomes or events may be identified through the value or range of values of a function, which is is denominated ‘random variable’. While the value of a random variable may be defined with a range of possible values, in contrast a deterministic variable assumes a definite value.

In reality, there is always some level of uncertainty associated with environmental influences and material parameters. To take this into consideration it is necessary to employ probabilistic methods and probabilistic analyses. These are necessary inputs to account for the level of acceptable risk in design and, ultimately, for the optimum allocation of available economic resources. This is done by accounting the uncertainty, or statistical parameters, associated with each individual random variable within the analysis. In other words, the numerical values of the random variables are associated with specific probability or probability measures (e.g. mean, standard deviation), which are then assigned according to certain rules, so called probability distributions.

There are some differences of opinion as to whether the weld metal is less resistant or more resistant relative to the base metal. However, it is well known that susceptibility to pitting depends on differences in the material composition and microstructure, and this may be influenced by the high temperatures involved in the welding process and the subsequent cooling rate. Both are affected by the welding procedures used (e.g. base metal indentifying equiaxed grains of ferrite and pearlite while weld zone comprise of columnar grains of acicular ferrite characterizing a quenched steel and heat affected area displaying a more finer grained region of equiaxed pearlite and Widmanstätten ferrite).

From an industrial point of view, corrosion is accounted for during the design phase by means of a corrosion allowance. Recent study (Chaves IA and Melchers RE 2011) shows that the corrosion observed in the base metal is less than that in the HAZ and this continues also long-term. These observations should give a degree of confidence for extrapolation of medium to longer term data.

Although the above discussion is confined largely to pitting corrosion as an independent deterioration mechanism, in practice corrosion is not an independent issue for risk and remaining life assessments. Corrosion interacts with applied stresses, fatigue, mechanical damage and, most importantly, with protective systems such as cathodic protection, paint coating and management practices. In practice these interactions cannot be ignored, even though the actual interactions are not in all cases fully understood. Evidently, these interactions for particular applications also provide a rich field for further research in which probabilistic models will be important. This is considered to be an exciting and demanding challenge.