



Minimizing Stress Corrosion Cracking by Matching Packer Fluid Chemistry with Tubular Metallurgy

Jeffrey S. McKennis and Thomas S. Carter (TETRA Technologies, Inc.)

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Abstract

In recent years environment-assisted cracking (EAC) has become a problem for oil and gas producers. Tubing failures have been attributed to the interaction of corrosive packer fluids with sensitive, stainless steel metallurgies under stress. Until now, owing to their complexity, EAC problems have been difficult to solve.

To understand the issues involved and to find solutions, TETRA and JFE, the leading producers of clear brine fluids (CBF) and martensitic stainless steel tubulars (MSS), have jointly developed an accelerated EAC test methodology that replicates the mechanisms of tubular failures in the field.

The methodology enables studies of packer fluid chemistries and tubular metallurgies to identify how diverse CBFs interact with various MSS. A key finding is that subtle differences in fluid and metal composition can contribute significantly to EAC, i.e., small differences often promote cracking problems.

The results of these studies will enable the matching of fluids and metallurgies thus minimizing the risk of failure, while enabling the operator to make selections that offer lower cost solutions.

Introduction

Stress Corrosion Cracking

In recent years an alarming number of well failures have occurred.^{e.g.,1-3} These can be catastrophic with failure occurring from several days to over a year from the start of production. With the loss of expensive tubing, accessories, and production time, as well as tubing replacement and workover expenses, the cost of a failure can run into the millions of dollars.

The failures observed have been attributed to environmentally assisted cracking (EAC) or, more specifically, to stress corrosion cracking of stainless steel pipe or accessories. The term EAC is used here to refer to stress induced failure regardless of the mechanism of action, for example, whether it involves a sulfide (SSC) or halide component (SCC).

Ironically, the increase in EAC is in large measure due to an increase in the use of various types of stainless steel metallurgies and corrosion resistant alloys (CRA) that were originally introduced to avoid general

corrosion from CO₂⁵ and/or H₂S in the more severe HPHT conditions. EAC is a localized corrosion process that requires the presence of a sensitive metallurgy like the CRAs. In fact, for EAC to be initiated, the synergistic interaction of three domains is required — a sensitive metallurgy, a corrosive environment, and stress (see Figure 1a). In the absence of any one of these domains, cracking will not occur.

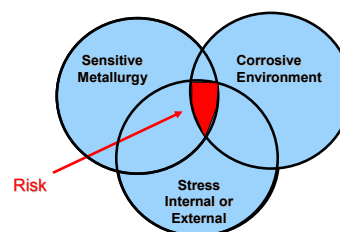


Fig. 1a – Risk of Stress Corrosion Cracking

The stress needed for EAC to occur can be either internal or external. Internal stresses are normally the result of the metal working processes applied in producing the tubing, e.g., annealing, cold working, etc. External stress is that which is induced operationally or by mechanical manipulation or handling of the tubulars from the mill to installation in the well. Examination of the numerous failures that have been reported reveals that external stress has not been found to be a major contributor to EAC. Rather the failures have been generally attributable to the interaction of the metallurgy with the corrosive environment of the packer fluid. Most of the failures observed occurred from the outside in — from the annulus side of the production string.

This realization is significant since tubulars are invariably chosen on the basis of their ability to stand up to production fluids and gases. Computer programs have in fact been designed and are commonly used to select the metallurgy given the composition of the production fluids. Generally it is much later in the well completion design that the compatibility of the tubulars and accessories with the packer fluid becomes a consideration.

Multi-Variable Field Failures

What do we really know about EAC, the metallurgy and fluids involved? Despite numerous and sundry papers about individual field failures and laboratory testing, our knowledge of the causes of stress corrosion cracking are still sketchy at best. This isn't surprising given the complexity of the problem. Numerous factors at one time or another have been implicated as playing a role, for example: the composition, strength, and hardness of the metallurgy, halide concentration, pH, additive levels, gas contamination (e.g., O₂, CO₂, and H₂S/sulfide content), and temperature. What is not clear is the relative importance of these factors and the complexity of their synergistic interactions.

Metallographic analysis has proven helpful in suggesting various mechanisms contributing to cracking, but it's becoming clearer that in many cases the actual mechanisms are more likely combinations or blends of these classical and discrete mechanisms. For example, the typical, low-temperature sulfide stress cracking (SSC) of martensitic steel may in some cases occur along with typical high-temperature, O₂-aggravated, chloride stress cracking (SCC) at temperatures much higher than normally associated with SSC.

In view of the above, the industry's understanding of the causes of EAC and ability to economically minimize its risk have been limited. Application of standard corrosion tests and experiments has not provided producers with consistent answers to assist them in accurately predicting how various tubular metallurgies and fluids will perform in the well. The relationships of variables in the cracking process, in many cases, have been more associative rather than causative. For example, a number of failures have occurred with packer fluids that have used thiocyanate ion as the corrosion inhibitor. Several lab tests have pointed to this as a contributor to failure under certain conditions.^{2,4} This association has been widely communicated throughout the industry. As a consequence, the use of thiocyanate ion has been significantly curtailed despite the assessment by some metallurgists that other factors were important in some of the failures. The citing of oxygen intrusion in the Erskine failure¹ is such a case. Furthermore, most of the failures that occurred with thiocyanate ion also contained an oxygen scavenger that was incompatible with the packer fluid rendering it ineffective, if not contributive to the failure. Indeed, thiocyanate ion need not be present since failures have occurred with thiocyanate-free packer fluids³. Some tests have even pointed to metallurgical compatibility with thiocyanate ion under certain conditions⁶.

Establishment of Co-Research Alliance

In view of the paucity of information on which to provide predictive behavior, a co-research alliance to obtain key answers has been established between two of the

world's leading manufacturers of MSS and CBF's. The technical alliance, referred to as the *ChemiMetallurgy*TM research program, has developed an accelerated laboratory test methodology for evaluating EAC susceptibility in the field. This methodology developed in association with InterCorr International, Inc., a leading international corrosion testing company, replicates the mechanisms of known field failures, and examines the interactions of metallurgies and fluids under 'real world' well conditions. The test protocol, a variation of NACE TM0177-96, Method C, uses highly stressed, non-machined C-rings cut from tubular stock, which are then immersed in a variety of proprietary stock fluids fortified with appropriate additives.

EAC Testing

Our testing activity is the most extensive program ever undertaken in the industry. Importantly, the research alliance of our companies brings a synergistic interface and sharing of technical knowledge between two, previously separate technical areas. The program started in early 2002 and by the end of the first quarter of 2005, more than 3000 individual tests will have been run. This extensive testing matrix includes more than 20 multi-density range fluids commonly used as completion or packer fluids, with 10-plus CRA metallurgies, miscellaneous additives, gases, and typical formation fluids at varying temperatures.

The information provided by these extensive 'real world' studies, will enable the establishment of a "Corrosion Susceptibility Index". This index will aid operators in rapidly assessing the relative compatibilities/incompatibilities of specific proprietary fluids and tubulars or accessories. The minimization of EAC risk achieved by the testing program is depicted in Figure 1b.

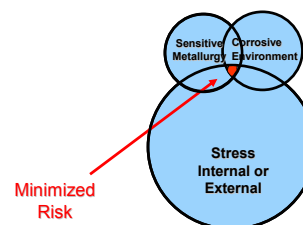


Fig. 1b – Minimizing Risk of Stress Corrosion Cracking

The information gained from these compatibility assessments will enable the integration of fluid and metallurgy choices providing economic benefits as well as a paradigm shift in well completion design. In addition to the evaluation of the compatibility of our current products, the alliance will provide a greater understanding of the key factors involved in EAC. This knowledge database will assist in the development of new products for the increasingly severe HPHT conditions of future wells.

Lessons Learned

The on-going study has yielded some surprising results, and has taken us in some unexpected new directions. Some of what has been learned to date tends to confront some previously held beliefs. Here are a few of the notable findings:

Bromide Ion versus Chloride Ion

Conventional wisdom has pointed to the preferential use of bromide fluids in place of chloride fluids. Indeed, many of the known failures in the field have occurred in calcium chloride¹⁻³. Additionally, miscellaneous lab testing and electrochemical measurement of pitting potentials of chloride and bromide fluids with chrome tubing have indicated a possible greater cracking susceptibility for chloride compared to bromide fluids.^{3,4,7,8} In contrast, our studies have shown that bromide fluids are not universally superior to chloride fluids. Sodium or calcium bromide fluids even in the absence of thiocyanate or sulfide ion at 300 °F have experienced failure.

Importance of O₂ Exclusion

Several studies have suggested the importance of minimizing oxygen to avoid EAC². In our studies, however, intrusion of oxygen even at 300 and 400 °F has had a less adverse effect than anticipated. However, unlike the norm for corrosion testing, we have conducted many tests with corrosion-inhibited fluids to replicate the real world situation. In several fluids at 300 °F, 13Cr 95 experiences greater pitting, but no cracking. HP1 13Cr110 and other metallurgies have experienced no increase in pitting or cracking. Studies to understand the effect of oxidants under various conditions are ongoing.

Concentrated Zinc Fluids

In view of the high acidity of concentrated zinc bromide fluids, it might be anticipated that EAC, specifically, stress induced hydrogen embrittlement or cracking, would be more prevalent with these fluids. This has not been the case; these fluids have proven to be quite resistant to cracking, even at 300-400 °F. In less acidic, less concentrated, formulated zinc fluids, no cracking at 350 °F has also been reported⁶.

Fluids & Metallurgies, Are They Generic?

Clear brine fluids and chrome metallurgy have long been regarded in the industry as generic — one manufacturer's brine or tubular being equivalent to another. The alliance's EAC testing, however, substantially contradicts this notion. We have observed that differences in raw material feed stocks, manufacturing processes, heat treatment procedures and formulation generate compositional product

variances. This is not surprising. However, particularly relevant is the significance of these subtle differences in fluid and metal composition on their susceptibility to EAC. The message from the testing to date is clear — small differences can promote significant cracking consequences.

Changing the Decision Sequence

The ability to predict tubing/packer fluid compatibility changes the opportunity not only to achieve a technically successful completion, but affords an opportunity to reduce the cost of the materials used. Normally, there is more than one tubing metallurgy indicated as being capable of handling produced fluids. Similarly, there will be more than one choice of packer fluids. However, the packer fluid choice will likely not be made until much later in the completion implementation.

Making this decision earlier in the completion design could provide significant economic benefits. Given choices of metallurgy paired with compatible packer fluids, lower cost and technically viable combinations could be identified and paired.

Conclusion

In order to minimize the risk of EAC and to provide better technical and economic choices in the selection of the metallurgy and fluids during the operator's well completion design, a unique technical research alliance was formed to conduct EAC testing of proprietary chrome metallurgies and clear brine fluids. This ongoing testing is assessing the mutual compatibilities of specific metals and fluids under 'real world' well conditions. With this knowledge base, potentially safer choices for tubular, accessory, and fluid selection can be made in a more integrated design decision. Testing to date points to the significance that 'subtle' differences in metal or fluid composition have on cracking susceptibility.

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