

TECHNICAL BULLETIN OF INDIAN SOCIETY FOR NON-DESTRUCTIVE TESTING (ISNT) THIRUVANANTHAPURAM CHAPTER

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January-March 2014

From
the Chairman's
Desk

Shri M.C. Dathan felicitated by ISNT, Thiruvananthapuram Chapter on being conferred Padmasree award by Govt. of India



Shri. M.C. Dathan, Director, LPSC
acknowledging the felicitation



A view of audience

Dear Members,

The science of Non Destructive Evaluation primarily developed from the need of the engineers to detect and screen out defects to prevent costly and catastrophic failures. In engineering, applications of NDE techniques have progressed from defect detection to defect characterisation, material property estimation, stress analysis etc. One can see that medical field has a lot of applications of various such noninvasive techniques and is in the forefront to apply them in the day to day life. This has been possible only due to the dedicated efforts in the laboratories to further the capability of the techniques by applying solutions based on an interdisciplinary approach. This approach necessarily requires frequent interactions between people to identify further problems and to foster ideas based on which solutions emerge.

ISNT plays a key role in helping people in different area meet together and create further awareness on different applications and possibilities. The programmes of our chapter are directed towards this. Our young engineers forum has contributed in exchanging information on the applications of the techniques and in conducting awareness on engineering failures by conducting appropriate lecture programmes. In one of our programmes, we also heard an absorbing lecture from a leading doctor, Dr. Kesavadas, SCTIMST, on the applications of NDE techniques for accurately determining causes of diseases and in performing corrective treatment.

Our chapter also had the joy of felicitating Sri Chandradattan, a life member, on being conferred with the prestigious Padmasree award.

On the anvil, are programmes with the involvement of academic institutions as well as refresher courses on the NDE techniques. The programmes require considerable time, efforts and participation of the members of the chapter, which fortunately had been available in the past, without hesitation. With the continuing support from members, I have full confidence that the chapter would achieve all these future goals.

With best wishes,

Saratchandran S
Chairman, Thiruvananthapuram Chapter

IMAGE

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Editorial Board

Editor

S. Sridhar

Member

Ajay Kumar

Publisher

Indian Society for
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Address for Correspondence

S. Sridhar
CNDTD/CCQG/CMSE
VSSC, Vattiyoorkavu
Thiruvananthapuram - 695013
Ph: 0471-2569157, 0471-2569219



Dear Members,

This is the first issue in 2014. The editorial committee wishes all members of ISNT Thiruvananthapuram Chapter Family "A very happy and prosperous 2014 in their professional and personal lives".

In this issue, the activities of the Chapter are covered by the Chairman and Secretary. Instead of reproducing their words, I thought that I will share some of my thoughts with all of you. Maybe you can respond and it can be printed in the next issue.

India's expertise in the area of Non Destructive Testing is very matured. This has been amply demonstrated by the successes of organisations like ISRO, DRDO, DAE and many others in public and private sectors. We have an excellent National Level NDT Professional body with Chapters covering most of our country. Annual National seminars are organised very meticulously and conducted. Training programmes are also conducted regularly. There is even an M Tech Course available. In short, NDT as a profession has been firmly established in India.

However, it is observed that in many organisations, most of the NDT equipments are imported. Yes, the level of R & D and investment which go into the development of high energy x ray machines, Thermography & C scan Ultrasonic Systems etc are high. But that does not mean we have to continue import, as there are problems in calibration and maintenance in such high end machines. While some agents are having expertise to offer AMCs, others are not having. The Indian industry has to be brought into this area; maybe with support from the ISNT parent body and National Institutions like ISRO, DRDO, DAE etc. Academic Institutions also may be considered.

India should be self sufficient in 'personal expertise' as well as in 'equipment manufacturing'.

I request members to share their views and suggestions.

Sridhar S



Felicitation to Padmasree M.C. Dathan

Sri MC Dathan, Director LPSC and a life member of ISNT, Thiruvananthapuram Chapter has been conferred with the prestigious Padmasree award by Govt. of India. Considering his long standing association with ISNT Thiruvananthapuram Chapter and the services rendered by him for the events organized by the Chapter, ISNT Thiruvananthapuram Chapter arranged a program to felicitate him. Program was arranged in hotel Classic Avenue on 17/02/2014 at 6.30 p.m. Shri Saratchandran, Chapter Chairman welcomed the gathering. Past Chairmen Shri R Sivaramakrishnan and Dr. Annamala Pillai delivered felicitation speeches.



Shri Saratchandran, Chapter Chairman, welcoming the gathering.

A Technical talk by Dr. Kesavadas

Dr. Kesavadas, Professor, Dept. of Radiology delivered a talk on "Medical Imaging Technology: Changing Paradigm in Medical Care". 70 members attended the program.



Dr. Kesavadas, Professor, Dept. of Radiology delivering the talk on "Medical Imaging Technology: Changing Paradigm in Medical care".



A view of audience

Stress Corrosion Cracking

Dr. S.V.S. Narayana Murty

Material Characterisation Division, Materials and Metallurgy Group
Vikram Sarabhai Space Center, Trivandrum
e-mail: susarla.murty@gmail.com



Catastrophic failure of a material by a synergistic action of stress and corrosion below its yield strength is termed 'stress corrosion cracking' (SCC). This is one of the most important mechanisms of failure of high strength materials. Many non-metallurgists may wonder why this term is so often heard in the parlance of failure mechanisms of aerospace materials. This is due to the fact that high specific strength materials are the preferred choice for aerospace designers, in view of their contributions to words payload gains. The high strength in materials is usually achieved by precipitation hardening of a supersaturated solid solution followed by artificial aging to peak strength. Under these conditions of peak aging, the material is microstructurally metastable and tendency for SCC is highest.

Therefore, utmost caution should be exercised while selecting high strength materials and where ever, not essential, it is better to avoid their usage in peak strength conditions.

What is SCC?

SCC is the conjoint action of stress and a corrosive environment which leads to the formation of a crack which would not have developed by the action of the stress or corrosive environment alone. The presence of a conducive microstructure facilitates the failure.

Why is SCC, worrisome?

SCC is an insidious form of corrosion; it produces a marked loss of mechanical strength with little metal loss; the damage is not obvious to casual inspection and the stress corrosion cracks can trigger mechanical

Technical Talk on "Stress Corrosion Cracking"

A technical talk on "Stress Corrosion Cracking" was arranged on 05/12/2013 at Hotel Nandanam Park, Trivandrum. Dr. S.V.S. Narayana Murty (Scientist/Engineer VSSC) delivered the lecture. Chapter Chairman Shri Saratchandran presided over the function. About 60 members attended the program. ISNT Chapter Secretary Shri S.Ratheesh delivered the welcome speech and Young Engineers' forum coordinator Shri Harikrishna proposed the vote of thanks.



Dr. S.V.S. Narayana Murty delivering the lecture on "Stress Corrosion Cracking".



A view of audience

fast fracture and catastrophic failure of components and structures.



Fig.1 Catastrophic failure of a Maraging steel bolt by SCC

What are the typical requirements for SCC?

The occurrence of SCC depends on the simultaneous requirement of (i) a susceptible material; (ii) an environment that causes SCC for that particular material, and (iii) sufficient tensile stress to induce SCC. Consequently, the occurrence of SCC is relatively rare, though failures can be very costly and destructive when they do occur.

Where does it occur typically?

Typical SCC failures are seen in high strength materials and components such as pressure vessels, highly stressed components and in systems when an excursion from normal operating conditions or the environment occurs.

Where do the stresses come from?

The stresses that cause SCC are either produced as a result of the use of the component in Service, assembly stresses, welding stresses or residual stresses introduced during manufacturing.

Where does the corrosive environment come from?

The environment can be either the service environment i.e. sea water or a temporary one caused by operations such as cleaning of the system which can leave a residue. While the presence of corrosive species is important, the concentration of the same is irrelevant. Sometimes exposure of an unprotected component to marine atmosphere could lead to SCC.

Is there a role for microstructure in SCC?

Microstructure of the material plays a critical role in both initiation and propagation of cracks during failure of a material. Local segregation in microstructure can promote initiation of pits and a conducive microstructure such as the presence of highly elongated grains can aid in the propagation of the cracks generated from beneath these pits.

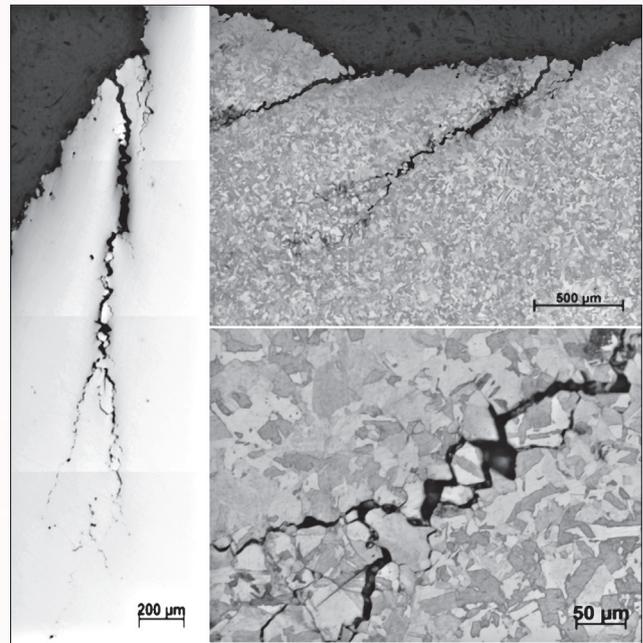


Fig.2 Typical nature of SCC cracks in M250 grade maraging steel

How is this different from 'normal' corrosion?

SCC is a corrosion mechanism that requires the pairing of a material with a very particular environment and the application of a tensile stress above a critical value. Corrosion can occur in other environments without SCC. Examples of well-known material/environment pairs are: stainless steels-chlorides; Aluminium alloys-chlorides; high strength steels hydrogen; copper alloys-ammonical solutions.

What causes SCC?

Three basic mechanisms of stress corrosion cracking have been identified as the causes of SCC, namely active path dissolution, hydrogen embrittlement and film-Induced cleavage.

Active path dissolution involves accelerated corrosion along a path of higher than normal corrosion susceptibility, with the bulk of the material typically being passive. The most common active path is the grain boundary, where segregation of impurity elements can make it marginally more difficult for passivation to occur. For example, when an austenitic stainless steel has been sensitised by precipitation of chromium carbide along the grain boundary, the local chromium concentration at the grain boundary will be reduced, and this region will be slightly less easily passivated. Consequently, a form of crevice corrosion can occur, whereby the grain boundary corrodes, with the specimen surface and the crack walls remaining passive. This process can occur in the absence of stress,

giving rise to intergranular corrosion that is uniformly distributed over the specimen. The effect of the applied stress is probably mainly to open up the cracks, thereby allowing easier diffusion of corrosion products away from the crack tip and allowing the crack tip to corrode faster.

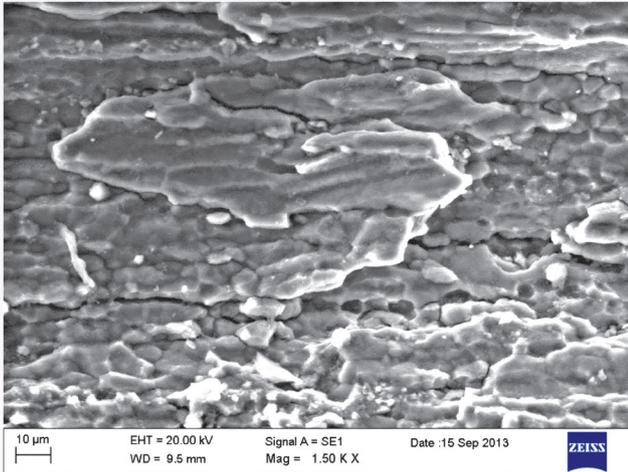


Fig.3 Intergranular SCC cracks in aluminium alloy AFNOR 7020

Hydrogen embrittlement is a phenomenon by which a ductile material gets embrittled due to the presence of hydrogen atoms and fails below its yield strength. Hydrogen dissolves in all metals to a moderate extent. It is a very small atom, and fits in between the metal atoms in the crystals of the metal. Consequently it can diffuse much more rapidly than larger atoms. For example, the diffusion coefficient for hydrogen in ferritic steel at room temperature is similar to the diffusion coefficient for salt in water. Hydrogen tends to be attracted to regions of high triaxial tensile stress where the metal structure is dilated. Thus, it is drawn to the regions ahead of cracks or notches that are under stress. The dissolved hydrogen then assists in

the fracture of the metal, possibly by making cleavage easier or possibly by assisting in the development of intense local plastic deformation. These effects lead to embrittlement of the metal; cracking may be either inter- or transgranular.

Film induced cleavage occurs when brittle films form as a result of corrosion in materials. If a normally ductile material is coated with a brittle film, then a crack initiated in that film can propagate into the ductile material for a small distance (around one micron) before being arrested by ductile blunting. If the brittle film has been formed by a corrosion process then it can reform on the blunted crack tip and the process can be repeated. The brittle films that are best-established as causing film-induced cleavage are de-alloyed layers (e.g. in brass). The film-induced cleavage process would normally be expected to give a transgranular fracture.

How can SCC be controlled?

Having understood that the reason for SCC failures are due to a combination of stress and corrosive species present together, the tactic lies in minimising/isolating them through:

- selecting a material that is not susceptible to the service environment and by ensuring that any changes to the environment caused are not detrimental.
- controlling the service stresses through careful design and minimising stress concentrations to keep them below the critical value. Residual stresses can be reduced by heat treatments and careful design during manufacturing.
- coating the material and effectively isolating the material from the environment.

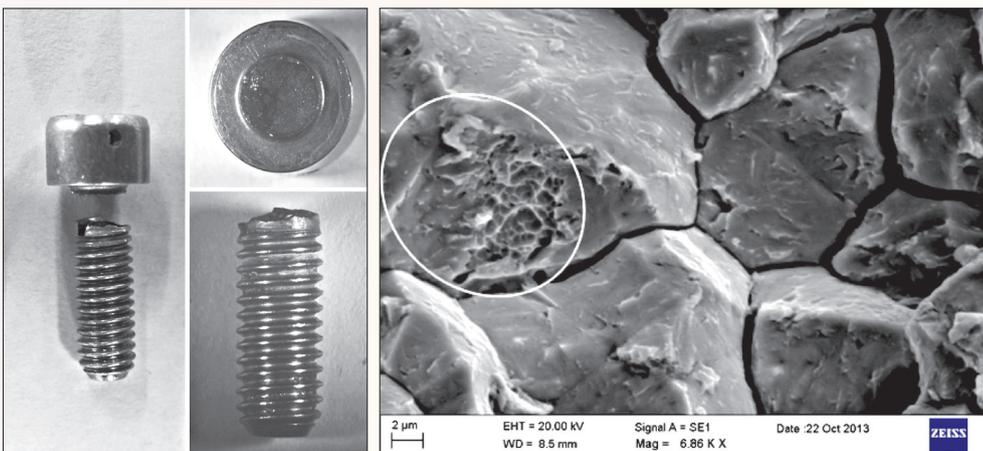


Fig.4 Typical hydrogen embrittlement of a fastener (left) and scanning electron micrograph of the fracture surface showing intergranular fracture with dimples on grain facets indicative of hydrogen embrittlement.

Selection of material: The first line of defence in controlling stress corrosion cracking is to be aware of the possibility at the design and construction stages itself. By choosing a material that is not susceptible to SCC in the service environment, and by processing and fabricating it correctly, subsequent SCC problems can be avoided. Unfortunately, this is not

always quite that simple to implement. Mechanical requirements, such as high yield strength, can be very difficult to reconcile with SCC resistance (especially where hydrogen embrittlement is involved). Finally, of course, Murphy's Law dictates that the materials that are resistant to SCC will almost inevitably be the most expensive (and that they will be found to be susceptible to SCC in your environment as soon as you have used them!).

Control of stress: As one of the requirements for stress corrosion cracking is the presence of stress in the components, one method of control is to eliminate that stress, or at least reduce it below the threshold stress for SCC. This is not usually feasible for working stresses (the stress that the component is intended to support), but it may be possible where the stress causing cracking is a residual stress introduced during welding or forming.

Residual stresses can be relieved by stress-relief annealing, and this is widely used for carbon steels. These have the advantage of a relatively high threshold stress for most environments, consequently it is relatively easy to reduce the residual stresses to a low enough level. In contrast austenitic stainless steels have a very low threshold stress for chloride SCC. This, combined with the high annealing temperatures that are necessary to avoid other problems, such as sensitisation and sigma phase embrittlement, means that stress relief is rarely successful as a method of controlling SCC for this system.

For large structures, for which full stress-relief annealing is difficult or impossible, partial stress relief around welds and other critical areas may be of value. However, this must be done in a controlled way to avoid creating new regions of high residual stress, and expert advice is advisable if this approach is adopted.

Stresses can also be relieved mechanically. For example, hydrostatic testing beyond yield will tend to 'even-out' the stresses and thereby reduce the peak residual stress. Similarly shot-peening or grit-blasting tend to introduce a surface compressive stress, and are beneficial for the control of SCC. One of the good examples of mechanical stress relieving is the high strength aluminium alloy tempers T651/652, where in the stress relieving is carried out by stretching or compression of the component. The uniformity with which these processes are applied is important. If, for example, only the weld region is shot-peened, damaging tensile stresses may be created at the border of the peened area.

Control of environment: The most direct way of controlling SCC through control of the environment is to remove or replace the component of the environment that is responsible for the problem. Unfortunately, it is relatively rare for this approach to be applicable. If the active species is present in an environment over which we have some control, then it may be feasible to remove the active species, although it may be difficult. In a situation, where the species responsible for cracking are a required component of the environment, the environmental control options consist of adding inhibitors, modifying the electrode potential of the metal, or isolating the metal from the environment with coatings.

Hydrogen embrittlement of high strength steels

All steels are affected by hydrogen, as is evidenced by the influence of hydrogen on corrosion fatigue crack growth, and the occurrence of hydrogen-induced cracking under the influence of very high hydrogen concentrations. However, hydrogen embrittlement under static load is only experienced in steels of relatively high strength. There is no hard-and-fast limit for the strength level above which problems will be experienced, as this will be a function of the amount of hydrogen in the steel, the applied stress, the severity of the stress concentration and the composition and microstructure of the steel. As a rough guide hydrogen embrittlement is unlikely for modern steels with yield strengths below 600 MPa,

and is likely to become a major problem above 1000 MPa. The hydrogen may be introduced into the steel by a number of routes, including welding, pickling, electroplating, exposure to hydrogen-containing gases and corrosion in service. The effects of hydrogen introduced into components prior to service may be reduced by baking for a few hours at around 200 °C. this allows some of the hydrogen to diffuse out of the steel while another fraction becomes bound to relatively harmless sites in the microstructure.

How to evaluate SCC proneness?

In essence, tests for stress corrosion cracking simply require the exposure of the stressed sample of the material or component in question to the environment of interest. However, there are various classes of test with differing objectives: Standard tests are generally designed to test a material for its susceptibility to SCC in an environment that is known to give problems, or to test components to determine whether they have the necessary combination of material properties and residual stress to suffer from cracking

Constant stress or constant displacement tests essentially describe a specimen and a loading method that stresses the specimen while exposed to the solution. The susceptibility to SCC is then assessed by the time taken for failure of the specimen, or the development of cracks on the surface of the specimen. A common constant displacement test uses a U-shaped specimen, produced by bending a flat plate, and then stressed by drawing the arms of the U together with a loading bolt (known as a U-bend test). Fracture mechanics tests use a specimen with a pre-existing crack (often produced by fatigue cycling).

The tests may be evaluated simply by recording the time to failure, but it is more common to measure the change in length of the crack with time, and thereby derive a graph of crack growth rate as a function of stress intensity factor. With a suitable loading arrangement and specimen geometry, it is possible to arrange for the stress intensity factor to fall as the crack grows, and this provides a useful method of estimating K_{ISCC} . The stress corrosion crack is initiated at a relatively high stress intensity factor, but as the crack grows the stress intensity factor falls, until the crack arrests at K_{ISCC} .

The slow strain rate test, or, more accurately, the constant extension rate test, applies a slow rate of extension to a specimen. This ensures that there is a continuing plastic strain at the surface of the specimen, and encourages the initiation and growth of stress corrosion cracks. The result of the test is evaluated in terms of the time taken for failure to occur, the extension at failure or the appearance of the fracture surface. This test has several advantages, including the limit to the time taken for the test (mechanical failure will inevitably occur even if no SCC occurs), and the relatively severe nature of the test, which means that it usually gives conservative results (i.e. failure is unlikely to occur in service if it does not occur in the test). The slow strain test is normally applied to smooth tensile specimens, although pre-cracked samples may also be used.

Immersion tests measure the progress of corrosion damage obtained from the immersion length within a corrosive environment, as well as other factors that can accelerate the corrosion process. These tests can involve alternative drying or immersions, such as in cases of cyclical tests. Moreover, test instrumentations may be included throughout immersion like electrochemical instrumentation connections in order to facilitate the measurements. An alternate immersion

test is a method for assessing the corrosion resistance of metals in salt solution. The test is particularly suitable for quality control during the manufacture of materials. The alternate immersion test applies to metals and all kinds of metallic and organic coatings.

Living with SCC:

It is often necessary to operate in conditions in which SCC is possible. This may result from a deliberate decision to use a system that may be subjected to SCC, but more commonly it arises because of unanticipated susceptibility. In determining both the probability of failure and the consequence of failure by cracking processes, the techniques of fracture mechanics may be very valuable. Fracture mechanics is concerned with the mechanical conditions at the tip of a crack, and the properties of the material that determine whether or not that crack will propagate. Whether or not a crack will propagate (in the absence of SCC effects) is determined by whether or not the applied stress intensity factor is greater than a critical value, known as the fracture toughness K_{IC} . Similarly it is generally found that SCC will only occur if K is greater than K_{ISCC} .

This provides us with a method of determining the likelihood of SCC failure of a given component, and indicates the requirements for crack detection during inspection. If our crack detection system can guarantee to find any crack of length a_{crit} or above, we can be reasonably confident that SCC failure is not likely to occur until such time as larger defects have grown (typically by pitting corrosion or corrosion fatigue).

If we are unable to detect cracks of size a_{crit} reliably, we must assume that such cracks exist, and base our inspection strategy on the time taken for the largest crack that we may fail to detect to grow to the size required to achieve K_{IC} . If the plateau crack growth rate is reasonably low this may give us an acceptable time between inspections, but for many systems the crack growth rate is too rapid and failure will occur in an unacceptably short time. Corrosion pits are common sites for the initiation of stress corrosion. To a first approximation a pit can be treated as a crack with the same cross-section, and a fracture mechanics approach used to determine the size of pit necessary to exceed K_{ISCC} and hence cause cracking. These techniques are routinely used for the assessment of fabricated components and structures for SCC.

Material Characterisation Division, VSSC has a number of test facilities for testing and analysing the stress corrosion cracking related phenomena. ♦