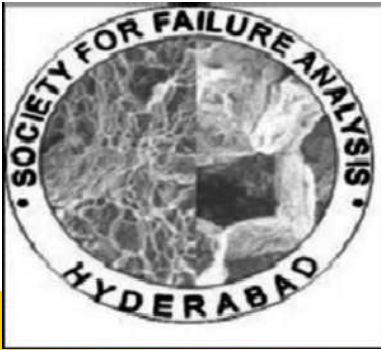




SFA Newsletter



Seasons Greetings!

message from our President



About SFA

Objectives

Local centers

Welcome you all to join as members of SFA! Please see page 21 for membership form and contact Secretary of SFA through email.

Dear readers,

Warm greetings! I am happy to find that the SFA newsletter is very well received as I find the feedbacks received clearly certifying this fact. I also understand that many interested failure analysts have proactively approached us to join the society as members which is a distinct sign marking the steady progress of the society. I appreciate the efforts by the editors recalling: *Individual commitment to a group effort - that is what makes a team work, a company work, a society work, a civilization work.*



K.Tamil Mani
PRESIDENT, SFA

**Send us
your feedback**

My sincere compliments to you on two counts; the first one is the "rising star" status conferred by a Padma Vibhushan. You are indeed a distinctly shining star in the horizons of the materials world. The second one is on the success of bringing out the second issue, which is as appealing as the first. With the zeal of the dynamic president and you, I feel that SFA has a great future. Keep it up! -

Dr.A.Venugopal Reddy

Thank you very much for sending me SFA January, 2011 Issue. I have made quick browse and find it excellent and highly stimulating. All the best to the endeavor of SFA. Best regards-

Dr PK De

Many thanks for your mail attaching the second News Letter of the Society for Failure Analysis. The articles are quite interesting. -

Dr.Malakondaiah

Thanks for sending me the newsletter. I have just glanced through it - it looks very impressive and informative. I must congratulate and compliment you for taking the initiative and creating the Society for Failure Analysis, which, I am sure, will go a long way in creating awareness and interest in this field, which is so vital to us. With my best wishes and regards-

Prof.S P Mehrotra

feed::back
we're all ears

feed::back
works!





From the Desk of Editors

"We learn an awful lot from failure. Failures tell you what you should not do in the future; successes, on the other hand, have very little to teach us", says Petroski

To read more about him:
www.nytimes.com/2006/05/02/science/02prof.html

Seasons Greetings! As you browse the columns of the third issue of the Newsletter of Society for Failure Analysis (SFA), efforts are underway to build the society in terms of membership. It is essential that local centres take active part in this respect. That can be clearly seen as in addition to regular articles, we have brought out the activities of the local centers. This ensures the excellent support for our activities from the local centres.

We also took efforts to publish the newsletter in IIM web site and in this respect; we thank Prof. I Manna for his immediate cooperation to upload the newsletter on IIM web site:

http://www.iim-india.net/images/SFA_Newsletter_2ndIssue_Jan_2011.pdf

We solicited articles from a few experts for the current issue. Considering the importance of environmental effects on failures, a few articles by experts highlighting corrosion related failures are presented as you may browse the newsletter. Further, importance risk analysis in electrical equipments was discussed in detail which form another interesting article in this issue.

We thank all the authors for their contributions to the current issue. We take this opportunity to appeal to the Indian industry to use SFA as a forum to share their experiences on trouble shooting. Also, we seek their support to sustain the newsletter by contributing articles and case studies.

A great way to add content to this newsletter is to include a calendar of upcoming events. The details of important forthcoming international and national events are included; so also the books recently published on the subject.

We value your comments, which really boost our enthusiasm to perform better. Therefore, as always, your views and comments, mailed to tjk@igcar.gov.in or param@igcar.gov.in are welcome. We wish you all free from failures and a joyful summer!

Kalpakkam (T.Jayakumar)
31-05-2011 (P .Parameswaran)
Editors





About the society

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Aims and Objectives of Society for Failure Analysis

The aims and objectives of the Society shall be:

To serve as National Society to promote, encourage and develop the growth of "Art and Science of Failure Analysis" and to stimulate interest in compilation of a database, for effective identification of root causes of failures and their prevention thereof.

To serve as a common forum for individuals, institutions, organizations and Industries interested in the above.

To disseminate information concerning developments both in India and abroad in the related fields.

To organize lectures, discussions, conferences, seminars, colloquia, courses related to failure analysis and to provide a valuable feed back on failure analysis covering design, materials, maintenance and manufacturing deficiencies / limitations.

To train personnel in investigation on failures of engineering components and their mitigation.

To identify and recommend areas for research and development work in the Country relating to failure analysis.

To establish liaison with Government, individuals, institutions and commercial bodies on failure analysis, methodologies and to advise on request.

To cooperate with other professional bodies having similar objectives.

To affiliate itself to appropriate international organization(s), for the promotion of common objectives and to represent them in India.

To organize regional chapters in different parts of the country as and when the need arises.

To do all such other acts as the Society may think necessary, incidental or conducive to the attainment of the aims and objectives of the Society.

Know your
local
centers



**SOCIETY FOR FAILURE ANALYSIS, MUMBAI****ONE-DAY SEMINAR ON 09 NOV 2010**

On the eve of World Quality Day and as a part of week long celebrations, Society for Failure Analysis, Mumbai Chapter conducted a one day Seminar on “Technical Investigations of Quality Failure and Check for Recurrence” in Mumbai on 09 Nov 2010 at Hotel J.M. Marriott, Mumbai and about 70 delegates attended the Seminar. The representatives of all the major Oil Industries like IOCL, BPCL, HPCL, RIL, Essar Oil and Avi-Oil, attended the seminar.

to raise awareness on important role, quality plays in ensuring nation's and organisation's prosperity. The following technical papers were presented:-

- Failure Analysis by Dr.A. Venugopala Reddy, Former Regional Director (Materials), Hyderabad
- Certification of Aviation Fuel by Shri Amarnath, Sc 'C', RCMA (F&F), CEMILAC, Bangalore
- Aviation Fuel from Plant to Plane by Shri RJ Patel & Shri PD Bahukhandi from IOCL

The aim of the Seminar was

Success consists of going from failure to failure without loss of enthusiasm. ~Winston Churchill





SOCIETY FOR FAILURE ANALYSIS, BANGALORE

ONE-DAY WORKSHOP ON 21 DEC 2010

The Bangalore Chapter of Society for Failure Analysis (SFA) conducted a one-day workshop on “failure analysis of aerospace engineering components” on 21 Dec 2010 at CEMILAC Auditorium. Workshop mainly dealt with the fundamentals of fracture, fracture mechanisms, failure analysis and prevention of failures. The following eminent personalities with their vast experience delivered the lectures.

a. “Process related Failures”
– Dr.R.R. Bhat, HAL,
Bangalore

b. “Failure Investigation using NDT” – Shri P Vijayraghavan, HAL, Bangalore

c. “Failures in Power Plant” – Dr Sita Ramu, CPRI, Bangalore

d. “Methodology of Failure Analysis” – Dr.S.K. Bhaumik, NAL, B’lore

e. “Failure Investigation of Kanishka” – Dr.V. Ramachandran

More than 100 delegates from DRDO, HAL, ADA, SAFRAN India and Private industries attended the One-Day Workshop.

Success and failure:
We think of them as opposites, but they're really not. They're companions - the hero and the sidekick.
~Laurence Shames





Corrosion Surveillance To Avoid Premature Failures Of Industrial Components During Fabrication And Storage

R.K.Dayal*

Former Head, Corrosion Science & Technology Division

Metallurgy and Materials Group

Indira Gandhi Centre for Atomic research, Kalpakkam

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Industrial components are fabricated based on appropriate materials selection, design, and processing and necessary surface modification. Therefore it has been a regular practice of controlling and monitoring them during service exposure to protect them from any deterioration. In addition, there are instances of corrosion taking place during fabrication and storage stages. It has been reported that many of these components face premature failures consequently. This is due to the fact that the environmental conditions, particularly at coastal sites are different from those encountered during service conditions. Improper surface treatments/ procedures followed during the fabrication of components may also make them susceptible to premature failures.

In power or chemical plants, austenitic stainless steel is a common choice of material because of its excellent combination of mechanical and uniform corrosion properties. But this material is highly prone to localised corrosion attack unless specific care is taken to avoid the causative factors. Therefore, it is of great significance to take appropriate measures during fabrication and storage stages of critical components particularly when these activities are carried out at coastal regions.

The environmental conditions of a coastal site are high humidity and air-borne salts containing chlorides. Besides corrosive saline environment, the components are also exposed to the heat of sun, wind, rain, dust etc. In such high humidity environment, diurnal changes in temperature can cause





If you shut your door to all errors, truth will be shut out. ~Rabindranath Tagore, *Stray Birds*, 1916

condensation/ evaporation of water leading to concentration of chlorides on exposed surfaces causing corrosion initiation.

There are certain harmful contaminants, which also induce corrosion attack on austenitic stainless steel surfaces in the humid chloride-containing environment. For example, surface contamination of iron particles can result in rusting, pitting and stress corrosion cracking. The sources of iron contamination are generally from the use of carbon steel or low alloy steel tools or wire brushes, cutting/grinding of carbon steel materials in the nearby area, use of iron/scale contaminated sand for blast cleaning, walking over on components with shoes having iron hobnails. Adhesives, oil film contamination can cause pitting and under deposit attack. This contamination can come from non-removal of stickers/adhesive films, surface not cleaned after making non-destructive tests. Halides (chlorides or fluorides) contamination can result in

pitting, intergranular corrosion and stress corrosion cracking. The halides contamination can come from pickling acid residue, ordinary water used for hydro-test or cleaning followed by inadequate DM water rinsing, LPT chemicals, chalks/ink used for marking.

In order to avoid corrosion failures in austenitic stainless steel components, certain established guidelines during handling of such components should be followed. These include specification on materials, appropriate parameters for processing and exposed environment. The exposed surface after fabrication should be well pickled and passivated with no surface contaminants.

Periodic corrosion surveillance is emphasised to ensure that the required guidelines are followed and also to find out if any corrosion initiation has occurred so that immediate corrective actions can be taken. Due to the presence of high humidity and chloride content in the coastal atmosphere, efforts should be made to store the components in enclosures without direct access to the coastal atmosphere. Ideally, all





Dare to be naive.
~Buckminster Fuller



equipment should be stored in closed area with humidity control by hot air blowing or installing dehumidifiers. However, if storage with controlled atmosphere is not available, equipment should be covered using polythene sheets and stored in covered sheds. The humidity of the local environment can be controlled in the range of 30-50%. Humidity indicator cards can be used to monitor changes in humidity levels inside the packing. Covering the components with polythene sheets, aluminium foils etc. will ensure that dust and other particulate matter will not settle on finished surfaces. These particulates provide ideal conditions for pick up of moisture and chloride from the atmosphere. Wherever possible, moisture and oxygen in the local environment can be minimised by nitrogen (95% purity) blanketing. At ambient temperature of 30-32 °C, with relative humidity of 30%, it corresponds to a dew point of less than 10 °C. The purity of nitrogen and moisture can be monitored periodically and maintained at desired levels. If required, the flushing should be

carried out to achieve the nitrogen purity and moisture limits.

Equipment under fabrication and storage should be inspected periodically for the presence of brown spots, surface defects and surface chloride levels etc. The inspectors should have adequate knowledge of corrosion and should see that the recommended procedures are followed to maintain its corrosion resistance and protection in the coastal environment. Thus, with adopting proper guidelines, protection procedures and regular corrosion surveillance, the premature failures of costly components can be avoided.

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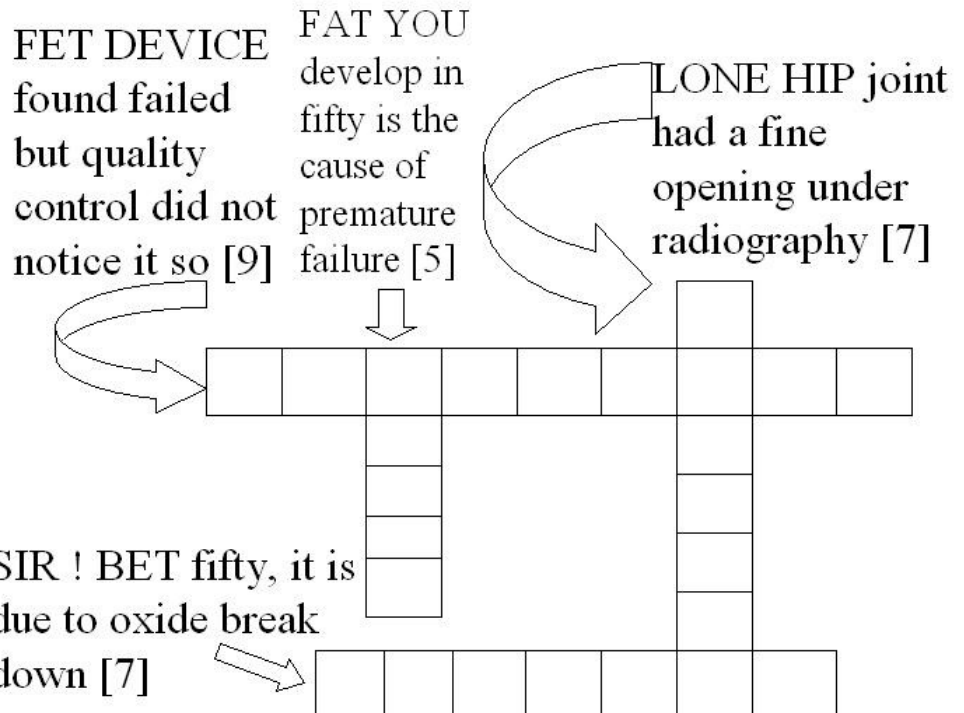


Lack of knowledge concerning all the factors and the failure to include them in our integral imposes false conclusions

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-



We encourage you to join the society, Kindly fill up the application form (enclosed at the end of the newsletter) and contact secretary: pjayapal59@yahoo.co.in ;



Failure of a Hydrodesulphuriser Reactor Welded Component

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Background

In a reputed petroleum refinery of the country, a certain critical elbow-to-flange weld in a hydrodesulphuriser reactor was found failed. The elbow and flange pieces were made of 5Cr-0.5Mo steel, which were circumferentially welded using TIG welding (first pass) and MMA welding (second pass) processes employing matching fillers. The weld was given a stress relieving treatment at 750°C for 1h (performed locally using induction coils). During normal operation, the feed to the reactor consists of a mixture of 1.4 wt.% sulphur diesel and 98.6% hydrogen at a hydrocarbon-to-hydrogen ratio of 1:250 (flow rate: 20m³/h, operating pressure: 55 kg/cm², operating temperature: 345°C). After about two months of continuous operation, the reactor was shut down due to

some process upset. While the normal shutdown practice is to put off the feed (both hydrocarbon and hydrogen) and purge the entire system with nitrogen, the plant engineers, however, chose, on this particular occasion, to put off the hydrocarbon supply alone and keep the reactor under 22 kg/cm² of hydrogen pressure, thinking that it would be a brief shutdown. However, things took a little longer and the reactor could only be started after nearly two days. Within a few hours after starting the reactor, the elbow-to-flange weld was found failed, hinted by a sudden pressure drop in the system.

Investigation

Figure1 shows the failed elbow-to-flange weld. Nearly 2/3rd of the circumferential weld was found cracked. The crack was located in the weld metal (as seen on the weld face). The remaining 1/3rd of the weld on the bottom half





of the elbow was intact, holding the flange and elbow portions together. Considering the nature of failure, crack origin was suspected to be in the upper half of the elbow. No anomalous features were noticed inside the elbow or flange.

To facilitate the investigation, the elbow-to-flange weld was broken into two pieces. Examination of the broken pieces revealed that cracking did not occur in the weld metal all through the thickness (Fig. 2). On the weld root side, the crack was located in the HAZ, close to the fusion boundary, all along the cracked weld portion. It was noticed that the crack, on the weld root side, shifted from elbow-side HAZ to flange-side HAZ and vice versa along the fractured weld portion. On the weld face side, however, the crack was located in the weld metal all along the cracked weld portion.

Visual examination further suggested that the crack was originated in the flange-side HAZ on the weld root side. Stereomicroscopic examination confirmed this suggestion. No

weld defects were noticed at the crack origin (Fig.3). In general, the fracture surface appeared relatively smooth on the bottom side of the weld in relation to the top portion. The smooth region corresponded to fracture in the HAZ, while the grainy region corresponded to fracture in the weld metal.

SEM examination of the fracture surface near the crack origin revealed predominantly intergranular fracture features with “crow-feet” patterns in both the smooth and grainy regions of the fracture surface (Fig.4). In the overall context of the current failure, these features suggest hydrogen embrittlement. The composition of the weld and base metals, determined using optical emission spectroscopy, was found to comply with the specified requirements.

Transverse sections, cut from the cracked weld at three different locations, were examined using optical microscopy. Figure 5 shows the various microstructural regions of the weld. As can be seen, the fracture line is located immediately adjacent to the fusion





boundary on the bottom side of the weld, while it is located in the weld metal towards the weld top surface. Figure 6 shows the fusion zone microstructure of the weld second pass. In the first pass, the weld microstructure appeared similar, but relatively finer compared to the second pass. While the observed microstructures are typical of 5Cr-0.5Mo welds in post-weld heat treated condition, the second pass, in particular showed a relatively harder-looking microstructure, as also the HAZ (Fig. 7). Microstructural examination along the fracture line indicated an irregular crack path, typical of intergranular fractures (Fig.8). Distinct secondary cracks were also noticed along the fracture line, which are commonly seen in hydrogen embrittlement failures.

Vickers hardness measurements were carried out in the weld metal, HAZ, and base material (load: 30 kg, time: 15 s). The weld metal (350 HV) and HAZ (390 HV) showed significantly higher hardness than

the base material (142 HV). Further, the measured weld metal and HAZ hardness values were higher than the maximum allowed hardness after post-weld heat treatment (240 BHN), as per the refinery's qualified welding procedure.

The results of this investigation show that there is nothing basically wrong with the welding procedures. Fusion welding of 5Cr-0.5Mo base materials using matching fillers (with preheat and interpass temperatures in the range of 225-300°C) is commonly done in petrochemical industries. A post-weld stress relief treatment in the range of 730-760°C for 2 to 4 hours is normally recommended. The results of this investigation, when put together with the service history, suggest that the cause of failure is hydrogen embrittlement. During normal operation of the reactor, hydrogen embrittlement is not an issue because of the relatively high service temperatures (345°C) – whatever hydrogen that diffuses into the metallic structure will quickly diffuse out. However,





when the reactor was last shutdown, only the hydrocarbon supply was put off (the system cools down to ambient temperature as a result) and the system was kept under a positive hydrogen pressure of 22 kg/cm², allowing significant diffusion and build up of hydrogen in the entire structure. The results of hardness tests explain why the failure occurred in the weld region. The weld metal and the HAZ showed higher hardness than the permissible maximum hardness. It is well known that harder microstructure aggravates the problem of hydrogen embrittlement.

In summary, two factors led to this failure: (i) keeping the system under hydrogen pressure at room temperature, and (ii) high weld metal and HAZ hardness. The former allowed significant diffusible hydrogen to build up in the system, while the latter increased the susceptibility of the weld region to hydrogen embrittlement failure. The local post-weld heat treatment attempted by the company with

induction coils did not seem to adequately reduce the weld metal and HAZ hardness.

Conclusion

Failure of elbow-to-flange weld occurred due to hydrogen embrittlement. Leaving the system under hydrogen pressure at room temperature for too long and high hardness in the weld region, as a consequence of inappropriate post-weld heat treatment, are responsible for the failure.

Recommendations

1. While shutting the reactor down, always put off the feed (both hydrocarbon and hydrogen) and purge the entire system with nitrogen. It may delay the reactor start-up a little bit, but it is the safest practice.
2. Increase the post-weld heat treatment soaking time from the existing minimum of one hour to a minimum of two hours. Review and firm up all the aspects of post-weld heat treatment and ensure that the weld metal and HAZ hardness are within the acceptable limits.





Reliability Centered Component Design for Minimizing Risk of Catastrophic Equipment Failures

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1.0 Introduction

To ensure that failures in service are minimized, modern process equipment & machine components are designed using sophisticated analytical tools drawn from a cross-spectrum of scientific disciplines ranging from solid mechanics and applied plasticity for a structural application to engineering electro-magnetics and heat transfer for an electrical engineering application. Of course, the common thread of materials science forms the core of all design activities in different disciplines. In addition, extensive use is made of mathematical tools such as optimization theory and probabilistic reliability to ensure that the components function robustly in randomly changing operational conditions.

For systematically designing high reliability engineering components,

an elaborate two stage procedure is usually deployed. In the first stage, the reliability of the candidate design concept is determined at the laboratory scale using independent property tests, and evaluation of performance indices along with their statistical confidence bounds. Similitude based testing (an accelerated test being one example) is also usually conducted in stage-I. Based on the results of stage-I, a small set of candidate design concepts are chosen for stage – II analyses. In the second stage, computer simulation studies are run in parallel with in-service proof testing, and explicit in-service reliabilities are determined. The results of stage-II are then used either as feedback for developing new design concepts or for choosing an existing design concept for mass scale production.

In the following sections, we present





some basic formulations for conducting analysis for the data generated in stage-I. These include formulation of an appropriate performance index as well as explicit reliability related formalisms. It is to be noted that the words “material” “component” and “sub-system” are all taken equivalent and are used interchangeably in the following text.

2.0 Formulation of Performance Index, PI for Analysis of Stage – I Data

For stage – I analyses, the single most important parameter to be evaluated is the performance index, PI, of the candidate material (s). We start this section by formulating an approach measure of this crucial engineering parameter. Let $P_1, P_2, \dots, P_n$, be “n” distinct and measurable material properties which are directly or indirectly related to the intended functionality of the proposed component. It may happen that for “m” of these properties ($m < n$), the desired attribute is that the values of each

of the properties be as low as possible (subject to a lower bound). Similarly, for the remaining “n-m” properties, the attributes are values as high as possible (subject to an upper bound). Based on these facts, it becomes possible to define scaled measures of all of the “n” properties as below.

Without loss of generality, let the first “m” properties be the ones with the minima attributes. Then, scaled measures for these properties can be defined as:

$$S_i^{\min} = \frac{P_i^{\min}}{P_i} ; i = 1 \text{ to } m \text{ -----(1)}$$

Where:

$$S_i^{\min} = \text{Scaled measure for } i^{\text{th}}$$

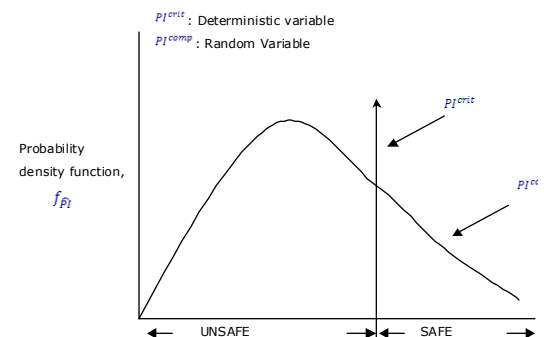


Fig. 1: A graphical representation of safe and unsafe regimes as per type – I reliability formulation.





property.

$P_i^{\min}$ = Lower bound value of i^{th} property.

P_i = Value of the i^{th} property.

Similarly, scaled measures for the remaining $n-m$ properties with maxima attributes are defined as:

$$S_j^{\max} = \frac{P_j}{P_j^{\max}}; j=m+1 \text{ to } n \text{ -----(2)}$$

Where:

$S_j^{\max}$ = Scaled measure for j^{th} property.

$P_j^{\max}$ = Lower bound value of j^{th} property.

P_j = Value of the j^{th} property.

Using a linear model, Eqs. (1) and (2) can now be incorporated into a formal expression for the performance index, PI as:

$$PI = \sum_{i=1}^m W_i S_i^{\min} + \sum_{j=m+1}^n W_j S_j^{\max} \text{ -----(3)}$$

In the above equation, the scale factors W_i and W_j are the weighting factors whose values

range from a minimum of zero to a maximum of one, subject to the following constraint.

$$\sum_{i=1}^m W_i + \sum_{j=m+1}^n W_j = 1 \text{ -----(4)}$$

Under this interpretation, the magnitude of a given weighting factor is directly proportional to the qualitative importance of the given property to the functionality of the component.

The weighting factors are easily determined using a paired comparison test. Non-linear rational polynomial models for the performance index can be easily formulated, too. However, such models should be only used, if it is known a-priori that the response surface of the performance index has an oscillatory character. Ideally, an independent theory to predict the order of the polynomial for a given application is required. However, such rigorous theories are generally not available.

3.0 Reliability Analysis of Stage-I Data

In stage-I, the final selection of





component design concepts for undergoing the next stage of proof testing is based on formulation and evaluation of two major parameters. The first parameter is a lower-bound critical value of the performance index (a scaled properties), which must be exceeded, in a statistical sense (based on numerical values of appropriate statistics and parameters characterizing the distribution function associated with the performance index) by all selected component design concepts. These lower and critical parameters are determined by an explicit engineering analysis of the component – environment interaction. The complete set of thermo-mechanical and electro-thermal loadings on the component are incorporated in these analyses using deterministic as well as probabilistic design concepts. The next major parameter for evaluation is the reliability of the selected component design concepts. This parameter can

be evaluated at two distinct levels. These are briefly discussed below:

3.1 Level – One Reliability

One of the most important parameters characterizing a modern engineering system is its functional reliability. The functional reliability of a system is defined as the probability that the system will perform adequately for the period intended, under a specific set of operating conditions. (1) The functional reliability of a system is an algebraic function of the reliabilities of the various sub-systems constituting the system as well as their inter-connection modes. Similarly, at the next level of hierarchy, the reliability of a sub-system is an algebraic transform relating the component level reliabilities and their explicit inter-connection modes (2, 3).

We define this measure to be the reliability calculated assuming the performance index of the component to be a random variable while the lower bound critical performance index is assumed to be a fixed variable, calculated using deterministic design concepts.

The reliability of the component is now easily defined using reliability engineering theory techniques (3, 4) as





a random variable called margin of safety, MS , as below.

$$MS = P I^{comp.} - P I^{crit.} \text{-----(5)}$$

The equation for the failure surface is then given by the condition:

$$P I^{comp.} - P I^{crit.} = 0 \text{-----(6)}$$

The region corresponding to $MS \leq 0$ is deemed unsafe, while the domain corresponding to $MS > 0$ is safe. The probability of failure, P_f , is then easily calculated as:

$$P_f = \int_0^{PI^{crit.}} f_{PI}(PI) d(PI) = P(PI \leq PI^{crit.}) \text{-----(7)}$$

From Eq. (7), the level-I reliability, R_I , is calculated as the complement of the probability of failure, P_f , as:

$$R_I \equiv 1 - P_f \text{-----(8)}$$

The integral in Eq (7) is usually evaluated by a numerical technique. In the happy circumstance that the performance index distribution can be modeled a normal distribution (when the left tail below zero and the right tail

above one contribute negligibly to the cumulative distribution function), the probability of failure, P_f , can be easily shown to be given by the following expression:

$$P_f = F\left[\frac{0 - \mu_{MS}}{\sigma_{MS}}\right] = F\left[\frac{PI^{crit.} - \mu_{PI^{comp.}}}{\sigma_{PI^{comp.}}}\right] \text{-----(9)}$$

Where

$F[\quad] =$ Distribution function of a standard normal random Variable with zero mean and a variance of unity.

From Eq. (9), it becomes possible to define a reliability index, β , as:

$$\beta = \frac{\mu_{MS}}{\sigma_{MS}} \text{-----(10)}$$

The reliability index is nothing but the inverse of the coefficient of variation. Thus, high variability corresponds to a low reliability index and vice versa. Incorporating Eq. (10) into Eq. (9), the level-I reliability, R_I , can be put in the following form:

$$R_I = 1 - F(-\beta) \text{-----(11)}$$

3.2 Level – Two Reliability

For level two reliability, the critical performance index, PI^{ent} , is also modeled as a stochastic variable.

Thus, level-two reliability is based on complete probabilistic analyses. This probability is easily computed as:





$$P_f = \int_0^1 f_{crit}(PI) F_{comp.}(PI) d(PI) \quad -- (12)$$

Where:

$f_{ent}(PI)$ = Probability density function of the critical performance index, PI^{ent}

$F_{comp}(PI)$ = Distribution function of the performance index of the component.

From Eq. (12), the level-two reliability of the component, R_2 , is obtained as:

$$R_2 = 1 - \int_0^1 f_{crit}(PI) d(PI) \quad -- (13)$$

Again, the integral in Eq. (13) has to be evaluated mostly by numerical techniques. However, in the happy circumstance of being able to approximate the two probability density functions by independent normal distributions, the failure probability is easily obtained in the following closed form expression.

$$\begin{aligned} P_f &= P([PI^{comp.} - PI^{crit.}] \leq 0) \\ &= F\left[\frac{0 - \mu_{MS}}{\sigma_{MS}}\right] \quad -- (14) \\ &= F\left[\frac{\mu_{PI}^{crit.} - \mu_{PI}^{comp.}}{\sqrt{\sigma_{PI}^{crit.}^2 + \sigma_{PI}^{comp.}^2}}\right] \end{aligned}$$

4.0. Case study relating to type-I reliability analysis for failure Investigations

“The probabilistic design/analysis technique has been successfully used at ERDA in understanding a number of component/equipment failures. One such interesting case pertains to a lot of threaded fasteners used in an industrial equipment. The selection of the fastener was based on the expectation (mean) value of the tensile strength of the bolts. During assembly, the bolts were pre-torqued to a fixed percentage of their mean tensile strength for generating the joint preload. A large number of bolts were found to fail during the pre-torquing operation. Review of the statistics of the tensile strength of the bolt lot indicated a low coefficient of variation of the tensile strength. Hence, the possibility of failure occurring due to variations in the tensile strength could be ruled out at a high level of statistical confidence.



However, when one factored in the expected probabilistic nature of the friction factor connecting the “pre-load generated in the bolt” to the applied torque, and used a probabilistic friction factor and deterministic tensile strength based - two parameter - stochastic design methodology, type-I reliability calculations indicated that the reliability of the bolt under the torquing operation being used was significantly low. In other words, analysis in a reliability setting helped in pinpointing the cause of the failure to be associated with an inadequately chosen value of the pre-torque at one sigma level of the friction factor connecting “pre-load generated in the bolt” to the applied torque. As a consequence, fasteners with friction factors lower than one sigma level of the mean value were being stressed beyond their ultimate tensile strength and

consequently failing during the assembly process itself.”

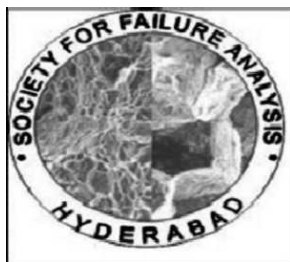
4.0 List Of References

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3. Siewiorek D. and Swarz R.: “The Theory and Practice of Reliable System Design”, Digital Press, Digital Equipment Corporation, Massachusetts, 1982.
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9. ULUSLARARASI KIRILMA KONFERANSI 9th INTERNATIONAL FRACTURE CONFERENCE 19-21 Ekim - October 2011 Yıldız Teknik Üniversitesi



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The Aim of the Conference

The "Fracture Conference" which has been held since 1991 has been a forum that getting an interest from scientific and industrial circles. The former 8th International Fracture Conference was held at Yıldız Technical University in Istanbul, Turkey. The 9th International Fracture Conference is again organized by Yıldız Technical University, İstanbul.

The aim of the conference is to present a scientific and technological overview of the current state of fracture and failure studies including theoretical and experimental works. It will also offer an opportunity to meet people from various backgrounds and have an exchange of views and practices with them on different aspect of the fracture.

Scope of Conference

- Brittle and ductile fracture
- Fracture behavior in static and dynamic loading
- Fracture mechanics
- Crack nucleation and propagation
- Fatigue, creep, fracture behavior of metallic, ceramic, polymeric, composite materials
- Fatigue, creep, fracture behavior of biomedical and nano materials
- Residual stresses, stress analysis
- Friction and wear properties of materials

Books

Dynamic Failure of Materials and Structures

Shukla, Arun; Ravichandran, Guruswami; Rajapakse, Yapa D.S. (Eds.) 2010,

Dynamic Failure of Materials and Structures discusses the topic of dynamic loadings and its effect on material and structural failure. Since dynamic loading problems are very difficult as compared to their static counterpart, relatively little is known about dynamic behavior of heterogeneous materials and structures.

Topics covered include the response of metallic, ceramic as well as polymeric composite materials to blast and shock loadings, impact loadings and failure of novel materials under more controlled dynamic loads. These include response of soft materials that are important in numerous applications but have very limited information available on their dynamic response. The topics of dynamic fracture and fragmentation that have reemerged in recent years have also been included. Both experimental as well as numerical aspects of material and structural response to dynamic loads are discussed.

Arun Shukla
Guruswami Ravichandran
Yapa D.S. Rajapakse
Editors

Dynamic Failure of Materials and Structures

Springer





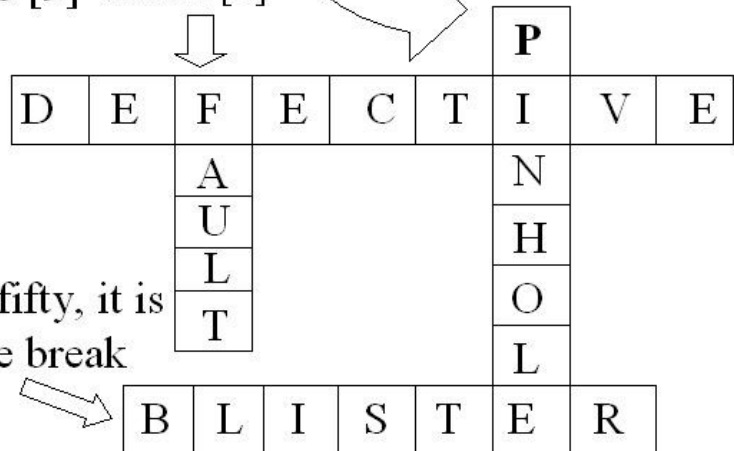
Answers to the crossword:

FET DEVICE
found failed
but quality
control did not
notice it so [9]

FAT YOU
develop in
fifty is the
cause of
premature
failure [5]

LONE HIP joint
had a fine
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