Issue 11 June 2014

SFA

About SFA

Objectives

Local centers

Welcome you all to join as members of SFA! Please find the membership form inside; kindly fill in and contact Secretary of SFA through email.

Experts and experiences:

Dr.S.Satyanarayanan, IGCAR, Kalpakkam

Smt. Swati Biswas, GTRE, Bangalore

Message from our President

Dear friends and colleagues,

Very nice to meet you all through this column. Greetings to all of you.

The scorching summer with the sun beating down with full vigour is almost over. People are unable to get over the hangover of the experiences of the holidays spent at hill stations! Fresh graduates bubbling with vivaciousness, enthusiasm and energy from engineering, science and commerce disciplines are vying with each other to get the best employment either at on-campus or off-campus interviews. The leisurely summer holidays are coming to an end; the students are keeping their cricket kit away and are looking for their backpacks. Anxious parents are running hither and thither for getting admission for their tiny tots in reputed schools. A new academic year is in the offing. A new dawn is on the horizon!!!

I have decided to discuss a pertinent topic entitled, "Forensic Engineering" with you as it deals with improving the performance or life of a component, preventing a similar failure and implementing lessons learnt and introducing safe operating practices, or establishing a root cause analysis of the failure. I am sure all of you will agree with me that these are the vital issues which are close to the heart of a scientist investigating a failure.

Forensic engineering entails the investigation of materials, products, structures, or components that fail or do not operate or function as intended; causing personal injury, damage to property or environment, or a loss of productivity. Forensic and failure investigation also deals with retracing processes and procedures leading to accidents in operation of equipment, machinery, vehicles, and systems. The term forensic is applied most commonly in legal cases, although the same cause and analyses apply more generally to engineering failures investigation too. The process of investigating and collecting data related to the materials, products, structures or components that failed, and the documentation of records, evidence, and documents received form important aspects of forensic engineering. These aspects involve inspections, collecting evidence, discussions with colleagues involved in design, manufacture, operation and maintenance of the failed system, measurements, developing models, analysing exemplar products, and conducting tests and simulations.

Many failure investigations focus on the immediate failure cause; i.e., for metals, the metallurgical or technical aspects of the failure. Going further, basic causes such as operational issues can be examined, e.g.,, a review of technical literature, such as corrosion and integrity management protocols, is performed to determine what aspects of the operations and maintenance contributed to the failure. A true "root cause" analysis takes the investigation one step further. The root cause analysis considers what management decisions were made, or not made, that contributed to the failure. By tracing the cause of the failure back to failures of management systems or processes, it becomes possible to prevent similar failures from occurring in the future. The performance can be improved by avoiding lost production time and repair or clean-up costs, providing a safer environment for employees and the public and preventing costly environmental damage. Thus, a comprehensive and inclusive "forensic concepts" based approach is essential in dealing with the analyses of failures. *Best wishes to all the readers!*

T. Jayakumar

Edited by: Dr.M.G.Pujar & Dr.P.Parameswaran, Metallurgy & Materials Group, IGCAR, Kalpakkam

From the Desk of Editors

Warm greetings! We are happy to present you the eleventh issue of the newsletter of Society for Failure Analysis (SFA).

Among the efforts taken to build the society over the last few months, activities by our local centres at various places, organizing workshops for inspiring the young engineering students along with various other professional bodies are some of them. These efforts have really yielded fruits that currently in the last few months, centres of SFA at Coimbatore and Chennai organized a national event and an international event respectively.We provide a glimpse of the programs conducted at these places in this issue as reports.

We have solicited articles from experts in the important area- fracture mechanics and failure analysis.

We thank the authors for their contributions which are truly significant as far as SFA is concerned.

We take this opportunity to appeal to the Indian industry to use SFA as a forum to share their experiences on trouble shooting. 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 along with; the books recently published on the topics of the subject.

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

You may visit our web site for your comments/suggestions or any queries : www.sfaindia.org

Kalpakkam (M G Pujar)
30-06-2014 (P .Parameswaran)
Editors

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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:, post your application with draft to Dr.N.Eswara Prasad, Regional Director, **RCMA,** CEMILAC, Kanchanbagh, Hyderabad, 500 058*

About the society

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

First International Conference on Structural Integrity (ICONS-2014)

The First International Conference on Structural Integrity (ICONS-2014) was conducted in Convention Center, Anupuram during February 4-7, 2014. ICONS-2014 was jointly organized by the Society for Failure Analysis (SFA), the Indian Institute of Metals Kalpakkam Chapter (IIM), the Indian Institute of Welding (IIW) and Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam. The main objective of ICONS-2014 was to provide a forum for engineers, scientists, academicians, industry experts, plant managers and regulatory personnel to discuss the recent advances and future directions in structural integrity encompassing design, material selection, stress analysis, manufacturing, materials evaluation, welding, quality assurance, microstructural characterization, corrosion, non-destructive evaluation, damage mechanics, failure analysis, life extension and other aspects that ensure safe and reliable operation of components in nuclear, defense, aircraft and other industries.

During the inaugural function held on 4th February, Dr.P.R.Vasudeva Rao, Distinguished Scientist & Director, IGCAR extended a warm welcome to all the speakers from abroad and India. He highlighted the need to have a conference series like this to bring researchers together to discuss the advances in structural integrity of engineering components and structures. Dr. T. Jayakumar, Distinguished Scientist & Director, Metallurgy & Materials Group, IGCAR and Chairman, ICONS-2014 and President, SFA, explained technical details about the conference. He stated that 272 research papers were being presented in 54 technical sessions and that there were 62 plenary talks by eminent international experts from 13 countries including UK, USA, South Korea, Germany, Czech Republic, Hungary, Japan, Portugal, Italy, Austria and Australia. He pointed out that ICONS-2014 had attracted delegates from R&D, academics as well as industries.

Shri S.S. Bajaj, Chairman, Atomic Energy Regulatory Board (AERB) inaugurated the conference. During the inaugural address, he highlighted the main role of structural integrity in ensuring safe and reliable operation of PHWRs as well as Kudankulam nuclear power plant and the important role played by the regulatory systems. He released the Souvenir of ICONS-2014 and gave the first copy to Dr. K. Tamilmani, Chief Executive, Center for Military Airworthiness & Certification (CEMILAC), Defence R&D Organisation (DRDO) and the past President, SFA. Dr. Tamilmani delivered the presidential address and emphasized the importance of material selection and imparting stringent quality assurance during manufacturing and assembly stages, especially in airborne military platforms. He released the proceedings of ICONS-2014 consisting of 185 full papers in the form of a CD.

ICONS-2014 was attended by 350 delegates. Four parallel sessions were conducted during February 4-7, 2014 with plenary and invited talks by eminent speakers on specific topics followed by contributory papers covering design, modelling, fatigue, fracture, creep, welding, NDE, corrosion, in-service inspection, condition monitoring, structural health monitoring, life extension, safety and reliability. All sessions were well attended and there were very good interactions among the participants. ICONS-2014 provided the participants a unique opportunity to present ideas and results of their R&D studies and to exchange technical knowledge in the area of structural integrity. It provided opportunities to forge international collaborations and research networks, which enabled the participants, especially 50 research scholars, to interact with eminent experts from India and abroad.

ICONS-2014 closing session was chaired by Dr. T. Jayakumar on February 7, 2014. Dr. David Smith, UK, Dr. Ward Rummel, USA, Dr. Raman Singh, Australia, Dr. G. Raghava, SERC, Chennai and CMDE Mohamed Salih, Indian Navy, New Delhi spoke and gave their feedback. They appreciated the arrangements and congratulated the organisers for successfully conducting the conference and expressed their desire to take part in future conferences. It was decided that the 2nd International Conference on Structural Integrity would be conducted during February 2017.

Welcome address by Dr.P.R.Vasudeva Rao, Director, IGCAR on the occasion of inauguration of ICONS-2014

Apparent failure may hold in its rough shell the germs of a success that will blossom in time, and bear fruit throughout eternity-
Frances Ellen Watkins Harper

Report on the "One Day Seminar on Topics in Failure Analysis" held at Amrita School of Engineering, Amrita University, Coimbatore , on 26th April, 2014.

The one -day event "Topics in Engineering Failure Analysis" was successfully conducted at Amrita University, Coimbatore. Prof Subba Rao, Amrita School of Engineering coordinated all the activities along with the wholehearted support of Prof.Shantanu Bhowmik of Aerospace Department and Professor C.Parameswaran, Director, Corporate and Industrial Relations and his team of highly dedicated staff. The day began with a brief inauguration by the lighting of lamp, welcome to speakers and an introduction to R &D efforts of Amrita School of Engineering by Prof Bhowmik , who is a Professor in Aerospace Engineering as well as Head of Research Division at Amrita. The seminar began with the first lecture by Sri.K.V.Kasiviswanathan who introduced the importance of failure analysis through several examples of catastrophic failures and then discussed a few case studies from his experiences, highlighted the importance of corrosion protection, systematic survey by NDTs, in-situ metallography and other issues.

The second lecture by Sri.S. Jalaldeen was comprehensive in bringing out the factors of design like various loadings, thermal stress, creep etc and the consequent failure modes under low and elevated temperatures like excessive deformation, ratcheting, buckling, flow induced vibration, fretting wear. His experience in dealing these issues was distinctly noticed when he discussed extensively on different forms of thermal stripping & Finite element analysis of critical Sodium cooled Fast Reactor (SFR) components and flow induced vibration.

The third lecture was by Dr.M.G.Pujar who started with an introduction to corrosion initially and then followed by various methods of mitigation like coatings, changing environment and corrosion protection methodologies. He highlighted the corrosion control by nine different methods in various components exposed to corrosive media.

The fourth lecture was by Dr.P.Parameswaran who briefly brought out the importance of microstructure in understanding the behaviour of materials and then continued with a few case studies which highlighted how microstructure enabled in understanding different mechanisms responsible for the radiation damage, creep of materials and discussed case studies of a few components that failed in sodium environment.

The fifth lecture was delivered by Dr.V.S.Srinivasan who introduced creep and fatigue and the associated damage mechanisms. He touched upon design of creep-resistant alloy through proper choice of alloying elements, crystal structure and microstructure to resist diffusion, restrict dislocation motion and grain boundary sliding etc. He introduced parametric approach which was essential for creep-life prediction and theta projection methodology. He discussed the interaction of creep and fatigue which could lead to a mixed mode of failure in engineering components during elevated temperature service. The sixth lecture was delivered by Smt. Swati Biswas from GTRE, Bangalore. She discussed a typical aero engine and its various parts, and materials etc. She mentioned that 37% of failures in aircrafts were from aero engines and that 50% of them failed through fatigue mode. She continued the discussion on failure modes of different components like turbine blades, casing, fan, disc, gears etc and highlighted a few case studies like turbine blades and gears of various types.

The final lecture was given by Dr B.P.C.Rao, IGCAR who brought out the essence of NDT methods and their applications in pre-service, post - assembly, in-service or remaining life assessment thus benefitting the plant availability, upgradation & life. He discussed a few case studies where conventional magnetic particle inspection was found to be useful, he further highlighted the advanced methods like GMR-based sensors for ropeway monitoring, intercontinental pipe line monitoring, digital radiography, deployment of IR tomography for intelligent welding and sensors based on acoustic emission for early detection of cracks for the integrity assessment of bridges.

The lectures were received very well with the excellent interaction of 60 delegates representing industry, faculties and students of research who had come from Trichy, Coimbatore regions. The vote of thanks was proposed by Prof Subba Rao who appreciated all the advisory members, Amrita Univ., speakers and the delegates.

Evaluation of DBTT and crack arrest toughness of P91 steel under dynamic loading conditions

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Whenever a material is chosen for an engineering application and it is processed, occurrence of flaws is not completely avoidable. Flaws may appear as microscopic cracks, voids, inclusions, weld defects, design discontinuities, and so on. Therefore, it is a common practice to assume that a flaw of a chosen dimension and employ fracture mechanics approach to design critical components. This approach uses the flaw dimension and features, component geometry and loading conditions to evaluate the fracture toughness which is the ability of a component containing a flaw to resist fracture. In general, the dynamics of cleavage fracture of ferritic steels consists of initiation, propagation and arrest of the crack. Thus fracture toughness parameters like (a) cleavage crack initiation toughness (K_{Jd}) and (b) crack arrest toughness (K_{IA}) have become important for designers while evaluating structural integrity of ferritic components used in power plants.

Traditionally the variation of K_{Jd} versus temperature and Ductile to Brittle Transition Temperature (DBTT) have been evaluated based on RT_{NDT} indexed ASME K_{IC}, K_{IR} [1] curve approaches. The indexing temperature RT_{NDT} is based on the Charpy energy (C_V) vs temperature curves of Charpy specimens and the Nil-Ductility Transition Temperature (*NDTT*) of drop weight specimens. The variation of lower bound fracture toughness with temperature is obtained as an empirical correlation based on a limited dataset (due to very large specimen size requirement) of A533 and A508 class reactor pressure vessel steels (RPVs). The ASME K_{IR} curve is given as [1] :

$K_{IR} = 29.4 + (13.675*\exp(0.026(T-RT_{NDT})))$

where T is the temperature .

Whilst this method has been successfully used to assess structural integrity, it suffers from two main drawbacks, namely, a) it is not based on direct evaluation of fracture toughness, and b) it does not account for the statistical distribution of toughness in the DBTT regime.

In recent decades, these drawbacks have been addressed by the reference temperature (T_o) based Master Curve approach which uses a three parameter Weibull statistical distribution of fracture toughness at a given temperature and an empirical distribution of median K_{Jd} with temperature. It is to be noted that 'T_o' is a measure of DBTT. This method is applicable to all ferritic steels having body centred cubic structure. However, this method as given in ASTM E1921-10e1 standard [2] is applicable only under quasi-static conditions. This causes difficulty due to constraint loss when evaluating T_o from small size Charpy specimens which are traditionally used in nuclear reactors as surveillance specimens. Higher constraint and conservative T_o can be obtained by testing at higher (impact) loading rates due to the increase in yield stress.

Another issue of importance is the increasing consideration of crack arrest toughness (K_{IA}) as a material property below which cleavage fracture does not occur. However, the major practical drawback is that K_{IA} is traditionally obtained from very large sized specimens. Hence, methods to obtain K_{IA} from small sized Charpy specimens will be of relevance to power plant industries.

P91 steel is one of the candidate materials being considered for in-core application in FBRs. Hence, there is a requirement to evaluate the material for structural integrity. Moreover, the increase in DBTT due to microstructural degradation caused by service exposure involving irradiation and long term exposure to high temperature also needs to be studied. The effect of various factors like high P-content which causes embrittlement, and cold work which results during the fabrication of the components also needs to be studied. The effect of thermal aging on DBTT is critical as changes in microstructure and precipitation of deleterious phases may result in embrittlement. Embrittlement in this case refers to decrease in initiation fracture toughness (K_{Jd}) / increase in T_o^{dy}.

In this study [3], the DBTT and crack arrest toughness have been studied for Normalized & Tempered, cold worked without ageing, and cold worked + aged P91 steel . Cold work levels of 5%, 10% and 15% reduction in area were imparted by rotary swaging at ambient temperature. Thermal aging was carried out at temperatures of 600 / 650°C for 5000 and 10000 h respectively. Impact testing of pre-cracked Charpy specimens was carried out at loading rates of 1.2 ± 0.1 m/s within the DBTT regime. A typical load-displacement plot for P91 steel showing cleavage crack initiation and arrest is given in Fig. 1. It can be distinctly observed that the crack initiation load is marked as P_F and crack arrest load is marked as P_{arrest} in the figure. The micro mechanisms of cleavage fracture and arrest were also studied.

The reference temperature under dynamic loading conditions (T_o^{dy}) for unaged P91 steel [4] was determined to be 8 to 10°C for N&T and cold worked material. Scanning Electron Microscopic (SEM) study of unaged P91 steel revealed grain boundary decohesion to be the cleavage crack initiation mechanism. Secondary Ion Mass Spectroscopic studies (SIMS) revealed P-segregation at grain boundaries explaining the crack initiation mechanism. P-embrittlement explains the lack of effect of cold work on T_o^{dy}.

The change in T_o^{dy} of cold worked P91 steel with aging has also been evaluated [5]. Thermal aging at 650 °C for 10000 hours resulted in an increase of 80 to 90°C *in* T_o^{dy}, while a modest increase of 20 -30 °C was correlated with aging for 5000/10000h at 600°C. Transmission Electron Microscopic (TEM) studies revealed a network of Laves phase (Fe_2,(Mo, Nb) type) of large (100-150 nm) and small size (20-30 nm) along grain boundaries explaining severe and moderate embrittlement.

K_{IA} for P91 steel has also been obtained from small sized Charpy

Failure is blindness to the strategic element in events; success is readiness for instant action when the opportune moment arrives. Newell D. Hillis

specimens [6]. Evaluation of crack arrest toughness (K_{IA}) requires determination of arrest load (P_{arrest}) and arrest length (a_{arrest}). While P_{arrest} can be determined from the load-displacement plot, there are no standard methodologies to obtain a_{arrest}. Distinguishing microstructural features were also not available to identify a_{arrest} due to the complex microstructure of this steel. A novel application of the analytical 'Key-Curve' technique has been employed to determine a_{arrest}. The "Key-Curve" correlates load, displacement and crack length in a multiplicative and separable manner as follows:

$$P = B{*}W{*}(b/W)^{\eta}{*}H(d/W)$$

where P is the load, B is the specimen thickness, W is the width, b is the ligament length and d is the total displacement.
For deeply cracked TPB specimens, $\eta = 2$. The function $H\ (d/W)$ has been expressed here as a power law. The general approach in applying the Key Curve has been to generate the constants of the above expression by fitting the curve between yield point and peak load (maximum in the curve) where the crack length corresponds to the initial crack length, a_0. The fitted Key Curve expression is applied to the load (P) and displacement (d) pairs at the point of interest (either for arrest length or final unbroken crack length) after the cleavage fracture, for determination of the ligament length (b) corresponding to that particular load and hence the crack length (a) for that load, expressed as W-b. The correctness of this method was confirmed by good agreement between calculated and measured final crack length of fully unbroken specimens. Since cleavage crack propagation and arrest is basically an elastically driven process, the Linear Elastic Fracture Mechanics (LEFM) formulation of K was used to obtain K_{IA}. The P_{arrest}, a_{arrest} and specimen dimensions were used as inputs to obtain K_{IA}. K_{IA} varied between 60-80 MPa√m. The micromechanism of crack arrest was studied using SEM and Electron Back Scatterred Diffraction (EBSD) studies. SEM revealed cleavage facets surrounded by ductile bands. The occurrence of crack arrest is explained by the presence of these ductile bands. The size of the cleavage facets indicate that ductile bands are formed at packet and prior austenitic grain boundaries. EBSD studies revealed the presence of a high percentage (>60%) of boundaries with high misorientation angles (>40°) explaining the occurrence of ductile bands.
The determination of T_o^{dy} and K_{IA} for P91 steel from small sized Charpy specimens under dynamic loading conditions would be useful from

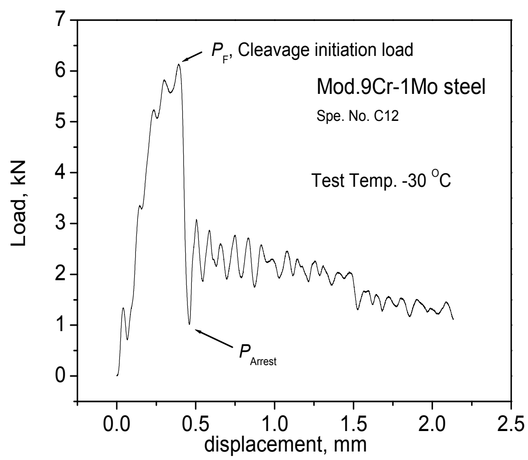

Fig 1. Typical load –displacement plot of P91 steel

design considerations due to the accompanying conservatism and relevance to the nuclear industry.

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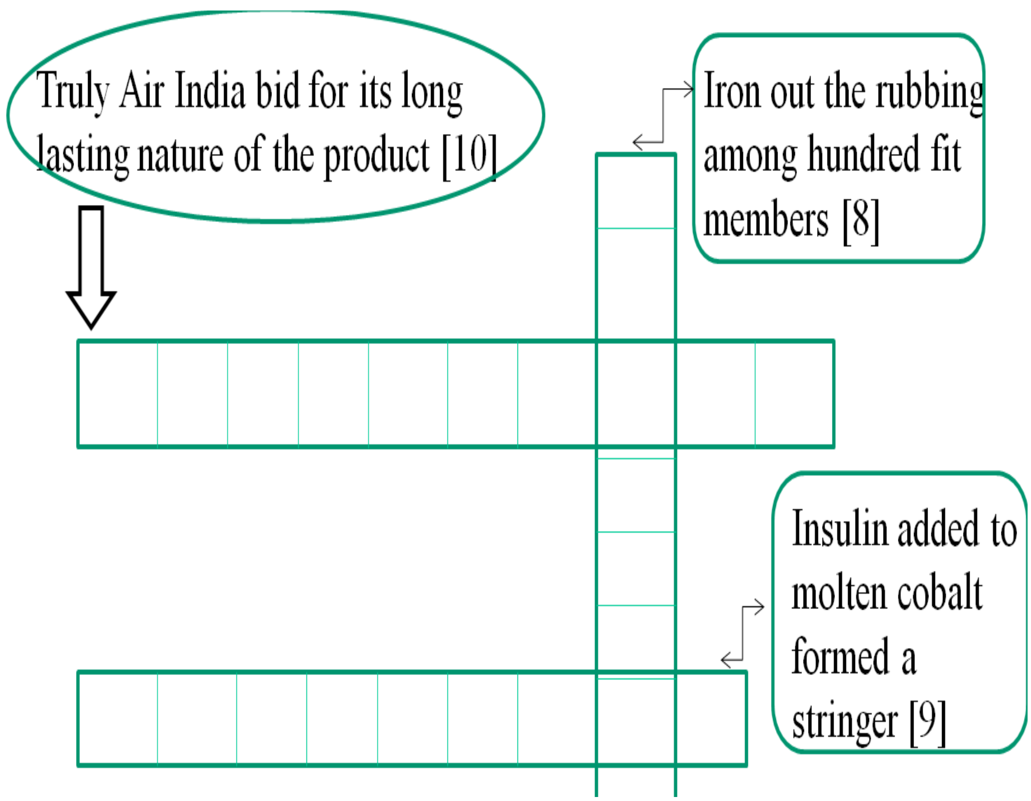
Cross word on failure analysis terminologies



Analysis of an aero-engine combustor fuel pipe failure in the weld joint during testing

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Abstract
A fuel pipe of an aero engine made of C263 superalloy was found to crack during testing. The pipe line was dismantled and crack was opened up to study the fracture mode. Fractography revealed failure by fatigue. Chemical heterogeneity at the crack origin was identified as the reason for crack initiation.
Keywords: superalloy, weld, aging treatment, fatigue, heterogeneity

1.Introduction

Present paper describes the failure of a connecting pipe, which was in use as assembled part of a combustor chamber in a developmental gas turbine engine. The function of the pipe was to supply fuel to the combustor. During testing of the engine, fuel leak was observed from the bottom of the engine. Vibration level was also high. The pipe was disassembled and subjected to detailed studies.

2. Observations

The photograph of the failed pipeline is shown in Fig.1. A crack was noticed at the tungsten inert gas (TIG) weld joint of pipe and ferrule. The crack was found to have propagated almost 75% of the outer circumference of the pipe.

2.1 Fractography Studies

Gross fractographic features of the cracked surface of the pipe exhibited progressive failure mode. A detailed analysis was carried out under a scanning electron microscope (SEM).

2.1.1 Scanning electron microscopy

An overview of the fractured surface is presented in Fig. 2. The fatigue crack initiation region is marked by 'A' in Fig. 2. The half moon shape of the beach marks (typical in fatigue failure) emanating from the point 'A' and progressing from the outer circumference towards the inner wall could be noticed. After initiation, the crack propagated almost 75-80% of the cross section of the pipe. The remaining area failed by overload at the time of crack opening.

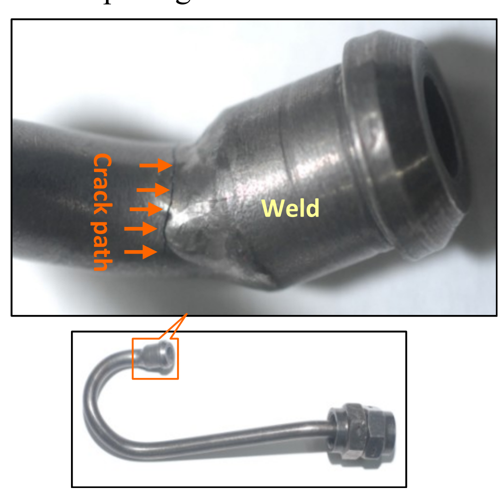

Fig. 1 Photograph of the cracked connecting pipe, crack path is indicated by arrows

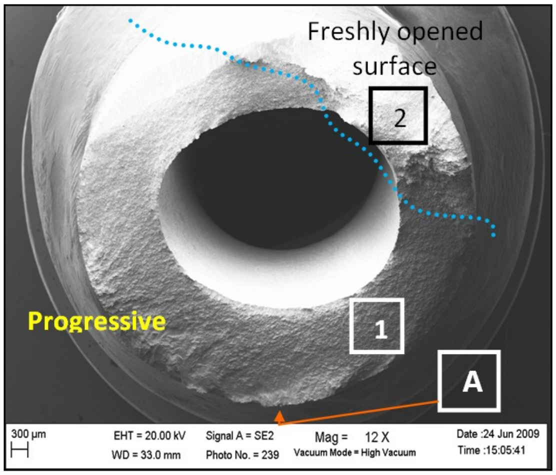

Fig. 2 Fractured surface of the ferrule under SEM; region failed by fatigue and overload has been demarcated by dotted line

The fractured surface was covered by thick oxide layer. However, striations were noticed at higher magnification in the region of fatigue failure (Fig. 3). Dimples were noticed in the freshly opened region indicating overload failure (Fig.4).

2.2 Microhardness survey & Optical Microscopy of the weld region

A longitudinal piece was obtained from the ferrule of the connecting pipe and prepared metallographically to study the hardness profile across the pipe-weld-ferrule. Microhardness profiling was carried out using 300g load and 10s dwell time. The base material hardness was found to be above 300 Vickers hardness number (VHN). In the weld region, hardness values were comparatively less, i.e. 264-280VHN (Fig.5). Even though, weld region hardness was comparatively less, the values were above the specified limit of solution treated & aged material - C263 (246VHN). Microstructure revealed presence of partially dissolved dendrites (Fig.6). Therefore, both

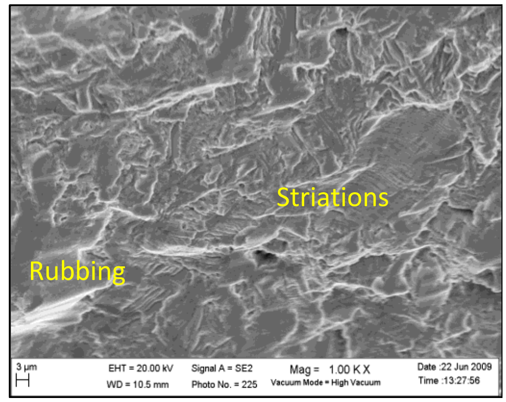

Fig. 3 SEM micrograph of fatigue crack propagation region (rectangle 1 in Fig. 2) exhibiting striations

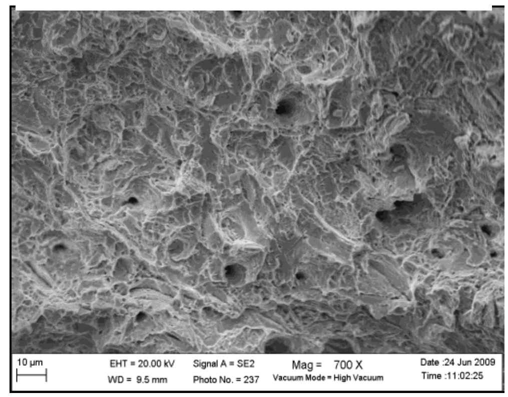

Fig. 4 SEM micrograph of freshly opened region (rectangle 2 in Fig. 2) showing dimples

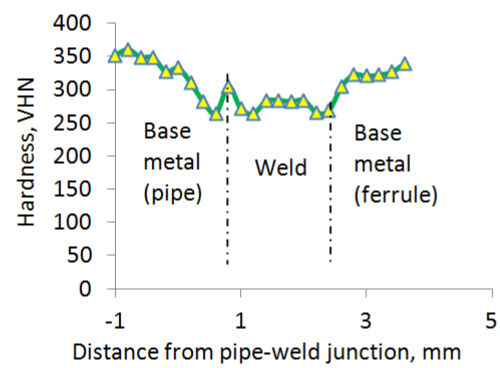

Fig. 5 Microhardness profile along the pipe-weld-ferrule

microstructure and hardness profile indicated that the failed pipe was subjected to aging treatment after welding operation. Hence, contribution of residual stresses to fatigue crack initiation was ruled out. ***2.3 Composition analysis***

Semi-quantitative energy dispersive spectrum (EDS) analysis was carried out in the fatigue crack initiation region. High concentration of Molybdenum (Mo) and Titanium (Ti) was recorded near the origin (Fig. 7). However, away from the crack origin, the material composition was conformed to C263. The results are compiled in Table 1 along with the standard composition of C-263 [1].

Table 1: Composition at fatigue crack origin, away from fatigue crack origin and standard composition of C-263 [1]

Elements	Weight %		
	At origin	Away from origin	Standard composition
Co	2.81	14.05	20
Cr	0.85	21.21	20
Mo	53.44	5.34	5.9
Ti	34.67	1.55	2.1
Al	-	-	0.5
Mn	-	-	0.4
C	-	-	0.06
Ni	8.23	56.06	51
Si	-	-	0.3

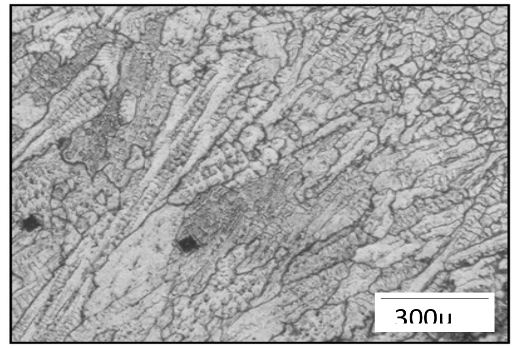

Fig. 6 Microstructure of the weld region in ferrule showing partially dissolved dendrites

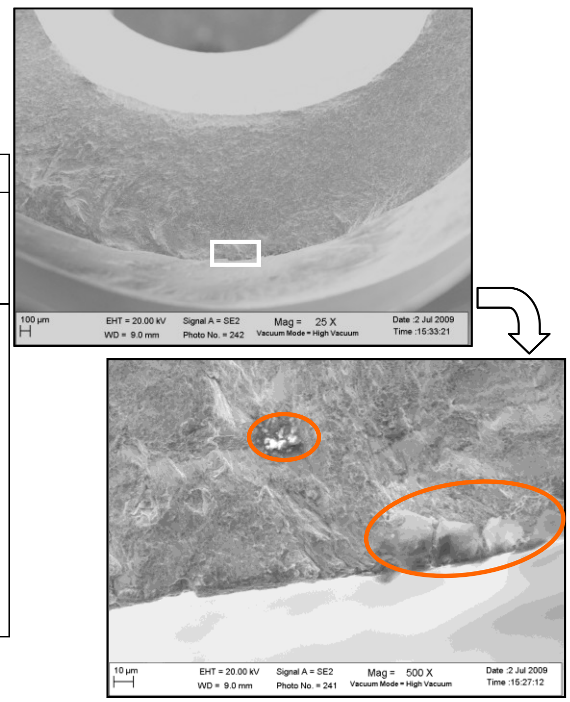

Fig.7. Fatigue crack origin exhibiting high Mo concentrations in the encircled region

3. Conclusions & Recommendations

Fatigue failure of the connecting pipe resulted by compositional heterogeneity at the crack origin. The filler rods used for welding C263 pipes were sectioned and composition analysis was carried out. Chemical heterogeneity observed at crack origin was noticed in the sectioned filler rod.

Acknowledgement

The authors express their gratitude to the Defence Research and Development Organization for the support to carry out this work. The authors are thankful to Director, GTRE for giving permission to publish these results. The authors are also grateful to Associate Director and Technical Director, Materials Group for their continuous encouragement. The help extended by the members of Machine Shop and other members of Materials Group is also acknowledged.

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Society for Failure Analysis

Application Form

Affix a passport size photograph

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1. **Name in Block Letters**

First Middle Last

2. **Date of birth**
3. **Father's Name/ Husband's Name**

4 **Present Occupation /Designation and office address:**	**Phone:** **Mobile:** **Fax:** **Email:**

5 **Academic & Professional Qualifications**:

6 **Home address:**	Phone: Mobile: Fax: E-mail

6. **Address for correspondence:** **office** ☐ **Home** ☐

7. **Professional Experience**:
8. **Endorsement by SFA Member**

Name	Membership No.	Signature

9. **Primary Field of Interest: (please mark 1,2,3 in the in order of preference**)

Strategic ☐	Power ☐	Foundry ☐	Welding ☐	Heavy industry ☐	transport ☐
Design & Failures ☐	Quality control ☐	Petrochemical ☐	Consultancy / services ☐	Materials and manufacturing	Education ☐

10. **Name of the Chapter you intend to be attached**________________________________
(Please refer to Chapters' list)
11. **Subscription details:**
Payment should be made by cheque / DD favoring **"Society for Failure Analysis"**, payable at Hyderabad. Outstation cheques not accepted.

Amount Rs. Cheque / D.D. No Dated

Bank Name Branch

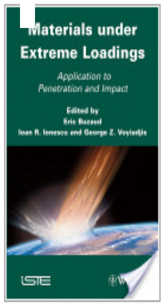
Category	Amount Payable		
	Admission Fee (One time)	Yearly Subscription	Total on joining
Member	----	Rs.200 (annual)	Rs.200/-
Life Member	----	Rs.1000	Rs.1000/-

12 **Declaration by the applicant**
If elected, I agree to accept to pay the prescribed yearly subscription, to abide by the Articles of Association of the Society and to promote its aims and objects.
Signature of the Applicant

13.	**Office Use Only**				
	Membership No.		Date of Enrolment		Chapter	
	Amount Paid (Rs)		Receipt No. / Date			

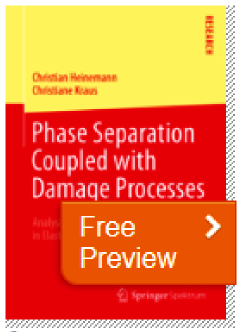
Books/ new journals

Materials under Extreme Loadings: Application to Penetration and Impact (Google eBook)



Georges Voyiadjis, Eric Buzaud, Ioan R. Ionescu
John Wiley & Sons, 04-Mar-2013 - Technology & Engineering

This book presents recent and cutting edge advances in our understanding of key aspects of the response of materials under extreme loads that take place during high velocity impact and penetration. The focus of the content is on the numerous challenges associated with characterization and modeling of complex interactions that occur during these highly dynamic events.



Springer Spektrum

Phase Separation Coupled with Damage Processes

Analysis of Phase Field Models in Elastic Media
Heinemann, Christian, **Kraus**, Christiane

2014, XII, 173 p. 11 illus., 10 illus. in color.

The authors explore a unifying model which couples phase separation and damage processes in a system of partial differential equations. The model has technological applications to solder materials where interactions of both phenomena have been observed and cannot be neglected for a realistic description. The equations are derived in a thermodynamically consistent framework and suitable weak formulations for various types of this coupled system are presented. In the main part, existence of weak solutions is proven and degenerate limits are investigated.

Contents

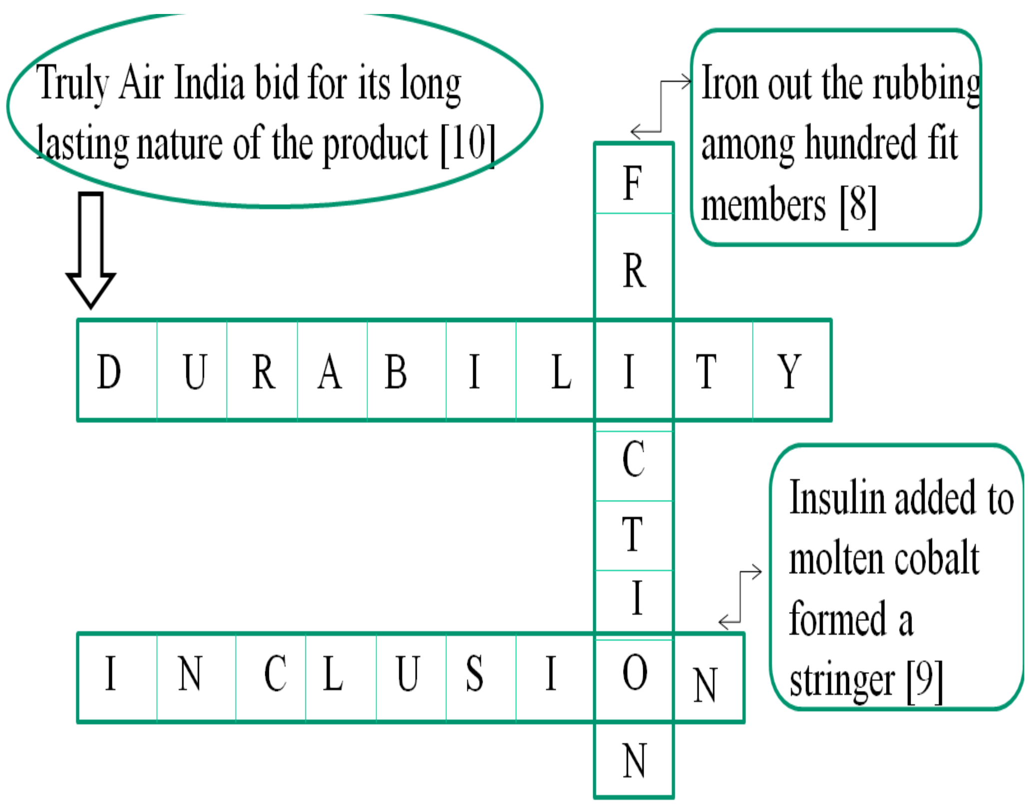
- Modeling of Phase Separation and Damage Processes
- Notion of Weak Solutions
- Existence of Weak Solutions
- Degenerate Limit

Target Groups

- Researchers, academics and scholars in the field of (applied) mathematics
- Material scientists in the field of modeling damaging processes

Events in the pipeline

Answer to Cross word



<u>Forth coming SFA events* for the current year (2014-15)</u>

1) **Theme Workshop On "Characterisation for and Select Case Studies of Failure Analysis", 19th July 2014 at RCMA (Materials), CEMILAC, Hyderabad**
2) **Workshop on Engineering Failure Analysis- NIT, Surathkal, Karnataka, 1-2, August 2014**
3) **Importance of Failure Investigation in aerospace materials, components and systems, CEMILAC, Bangalore, 6th Sept. 2014**
4) **Workshop on Service Performance of engineering materials, IIT Rourkee, Jan 2015.**

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