SFA Newsletter

Seasons Greetings!

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 Sandeep Bhattacharya

Sri.N.G.Muralidharan

message from our President

Dear readers,

Warm seasons greetings! I am happy to find the fourth issue of SFA newsletter rolling out following the Dussera and deepavali celebrations in India. The seasonal celebrations call for honest efforts in whatever we do and willingness to radiate peace and love wherever we go.

It is reiterating to say that the newsletter is well received by many. However it is a welcome sign that many interested failure analysts have proactively approached us to join the society as members, initiate their own centres at their places and conduct meetings under the SFA banner, which is a distinct mark as far as the steady progress of the society is concerned.

I must certainly appreciate the efforts by the office bearers of SFA recalling Benjamin Disraeli: *The secret of success is constancy to purpose."*

Happy Seasonal Greetings!

K.Tamil Mani
PRESIDENT, SFA

Edited by: Dr.T.Jayakumar & Dr.P.Parameswaran, Metallurgy & Materials Group, IGCAR, Kalpakkam

From the Desk of Editors

Seasons Greetings! As you browse the columns of the fourth issue of the Newsletter of Society for Failure Analysis (SFA), efforts are underway to build the society in terms of membership. We are getting ready to inaugurate our local centres at various places. 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 our website and in this respect, we thank the efforts by Dr Eswara Prasad who had worked out with professionals to build a nice internet site for our society. You may visit the site and give us your valuable comments and feedback for further improvements:

www.sfaindia.org

We solicited articles for the current issue from a few experienced failure analysts of our country who had worked on many case histories.

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 advertisements, 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 winter!

Kalpakkam (T.Jayakumar)
30-09-2011 (P .Parameswaran)
Editors

*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; alternatively, post your application with draft to Dr Eswara Prasad, Regional Director, **RCMA,** CEMILAC, Kanchanbagh, Hyderabad, 5500 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

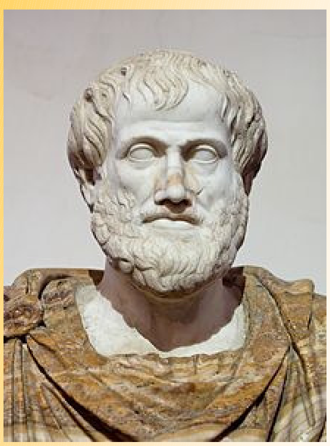
Society for Failure Analysis

Society for Failure analysis (SFA) organized its first lecture on 26th May 2011 at IGCAR, Kalpakkam when Dr.S.Ranganthan, Professor Emeritus, Indian Institute of Science, Bangalore and the eminent metallurgist of the country lectured on: *Materials, civilizations and choices*.

Recalling his association with failure analysts of National Aeronautical laboratory like Dr V.Ramachandran, Dr.A.C.Raghuram and Dr.R.V.Krishnan, Prof. Ranganathan emphasized that the selection of material is very essential in avoiding premature failures. Thereafter, Prof Ranganathan started describing the evolution of materials alongwith man as depicted by the ages like stone, bronze, copper and so on. He touched upon the materials tetrahedron and the important elements in the choice of materials particularly with reference to itsimpact on environmental factors like carbon dioxide, water and so on. He further elaborated the need of the hour is to make the right choice of materials considering the environmental impact of the use of materials.

The lecture evoked a lot of interest on the participants who posed interesting questions right from: (i) why Indian industry lags with reference to European sectors, particularly in metallurgical practices (ii) population growth alongwith its growing needson materials (iii) need for interaction between society and metallurgists, which Prof.Ranganthan answered with enthusiasm and further added that he has been taking efforts to teach science to the students who deal more with social studies.

It is possible to fail in many ways, while to succeed is possible only in one way - Aristotle



"No one in the history of civilization has shaped our understanding of science and natural philosophy more than the great Greek philosopher and scientist Aristotle.

To begin to think with purpose is to enter the ranks of those strong ones who only recognize failure as one of the pathways to attainment- **James Allen**

An Investigation on the Failure of Inner Cover of a Batch Annealing Furnace

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Abstract

Bulging of an inner cover made up of AISI 309S austenitic stainless steel of a batch annealing furnace (BAF) in a cold rolling mill has been investigated. Inner cover envelopes the cold rolled (CR) coils to be annealed and shields the coils from direct heating by the burners on the heating hood surrounding the inner cover. Visual inspection reveals deposition of soot at the inner surface, microstructural examination and EDS analysis indicate the formation of carbide network and sigma phase in the matrix, and micro-hardness profile shows gradual increase in hardness values from the outer surface to the inner surface. Analyses of the results suggest that carbon from the soot deposited at the inner surface diffuses into the inner cover matrix favouring the formation of carbide network at the temperature making the matrix lean. Depletion of alloying elements from the matrix deteriorates the creep resistance properties of the inner cover material making it prone to bulging.

1. Introduction

In a cold rolling mill (CRM), hot rolled steel strips are rolled at room temperature to improve the surface quality and mechanical properties of the sheets for their further processing. The cold rolled (CR) coils like extra deep drawing quality and interstitial-free steel sheets which are primarily used in the automotive industry are annealed under hydrogen atmosphere in batch annealing furnaces to render formability and shape flexibility in them. The coils are stacked on a base, one after another, separated by convector plates. An inner cover envelopes the CR coils to be annealed and a heating hood is put over the inner cover. The burners are on the heating hood surrounding the inner cover which gets heated up. The inner cover shields the coils from direct heating. Hydrogen gas circulates inside the inner cover and the coils are heated. The total annealing time varies in the range of 30 to 60 hours depending on the grades of steels. The shell temperature of inner cover near the burner zone is around 900 - 1000°C. The inner covers are found to bulge out near the burner zone within 2 to 3 years of service. These premature failures of the inner covers involve huge costs considering only the replacement of the damaged materials. The availability of the furnaces also gets affected due to this problem. The primary aim of this investigation is to find out the root cause of bulging of the inner covers of the batch annealing furnaces.

2. Plant Visit and Visual Inspection of the Samples

A failed inner cover and a heating hood are shown in Fig.1. The height of an inner cover is around 7 m. There are burners on the heating hood at two different height levels of 1.2 and 1.8 m. There are 6 burners at each height level with an angle of 45° to the tangent of the hood circumference. The burner uses desulphurised coke-oven gas as a fuel. The inner cover skin temperature reaches around 900 - 1000°C near the burner zone. The bulged out bottom part of the inner cover adjacent to the burner zone is shown in Fig. 1. Details of various samples collected from the failed inner cover for investigation are as follows: (a) two samples from the bulged zone (BZ) at the bottom part referred as BZ-1 and BZ-2, (b) two samples from the top part away from the bulged zone (ABZ) referred as ABZ-1 and ABZ-2, (c) one sample from unused plate material used for inner cover manufacturing. A typical sample collected from the bulged out bottom part of the inner cover is shown in Fig. 2(a). Deposition of soot (carbon) is observed at the inner surface of the sample as shown in Fig. 2(b). Soot deposition is caused due to the cracking of hydrocarbons of the rolling oils on the coils at the annealing

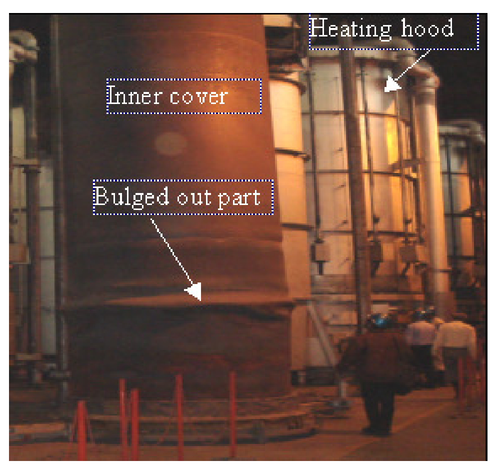


Fig.1 General view of a bulged out inner cover and a heating hood

temperature inside the cover.

3. Experimental Procedure and Results

3.1 Compositional Analysis

Chemical analyses of the samples collected from the inner cover were carried out both at the inner and outer surfaces using X-ray fluorescence (XRF) spectroscopy; carbon (C) and sulphur (S) content of the samples were determined using combustion infrared technique. The obtained chemical analyses of the samples are compiled in Table 1. Samples from bulged out bottom part (BZ-1 and BZ-2) exhibit higher carbon content at the inner surfaces compared to their outer surfaces while samples away from the bulged zone (ABZ-1 and ABZ-2) exhibit no such difference in carbon content between inner and outer surfaces. The chemical analysis of unused plate material is found to be similar to those of outer and inner surfaces of ABZ and outer part of BZ and conforming to their specification of AISI 309S grade of austenitic stainless steel. The higher carbon content at the inner surface of BZ is due to carburizing attack from the soot deposited on it, which generally takes place at the temperature range of 840 to 930°C. Top part of the inner cover, away from the burners, does not suffer from carburization attack because of lower shell temperature.

We don't grow unless we take risks. Any successful company is riddled with failures **-James E. Burke**

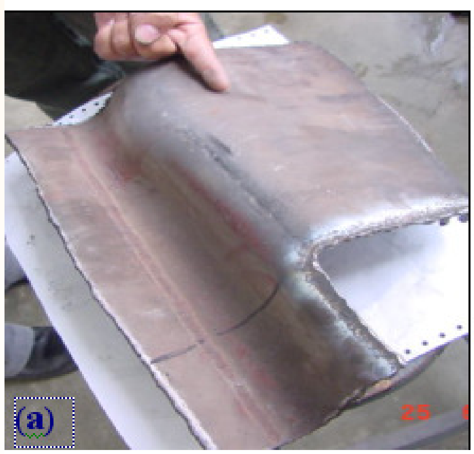
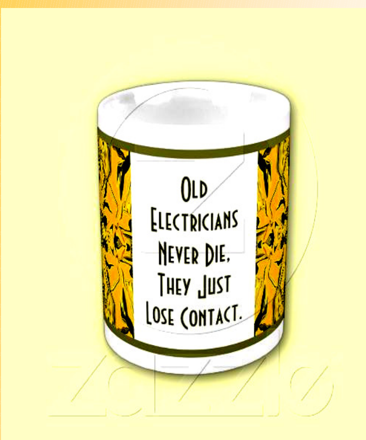


Fig.2 (a) Sample collected from bulged out part, (b) Deposition of soot at the inner surface

Table 1: Chemical analyses of the samples collected from various zones (wt.%) of inner cover

Sample	Surface	C	Mn	S	P	Si	Cr	Ni
Sample-1 Bulged Zone	Inner	0.70	1.10	0.005	0.024	0.49	21.7	12.1
	Outer	0.06	1.16	0.004	0.023	0.45	22.4	12
Sample-2 Bulged Zone	Inner	0.40	1.14	0.002	0.013	1.8	19.25	11
	Outer	0.059	1.17	0.002	0.021	1.8	19.25	11.1
Sample-1 Away from Bulged Zone	Inner	0.062	1.24	0.003	0.026	0.54	22.8	11.1
	Outer	0.06	1.19	0.004	0.024	0.55	22.3	11
Sample-2 Away from Bulged Zone	Inner	0.053	1.17	0.002	0.021	1.8	19.25	13
	Outer	0.052	1.17	0.002	0.021	1.8	19.25	12.5
Unused Plate	–	0.060	1.56	0.003	0.027	0.27	22.13	12
Spec. AISI 309S	–	0.08 max	2 max	0.03	0.045	0.75	22/24	12/15



3.2 Microstructural Examination

Small specimens were cut across the thickness of the samples for macro- and microstructural examinations at the cross-sections. These small specimens were then mounted with resign, ground, and polished using standard metallographic technique. The polished specimens were etched with villela's reagent to reveal the microstructures. The macrostructures at the cross-sections of the specimens from BZ and ABZ are shown in Fig. 3(a) and Fig. 3(b), respectively. The macrostructure at the cross-section of BZ exhibits a bright narrow band at the inner surface as shown in Fig. 3(a) while that of ABZ does not exhibit any such band (Fig. 3(b)). Microstructural examination at the inner side (narrow band) of the cross-section of BZ exhibits formation of severe carbide network as shown in Fig. 4(a). Formation of carbide network is favored due to carburization attack [1] at the inner surface of BZ adjacent to the burner zone where the shell temperature is higher (900-1000°C); this makes the cover matrix lean in alloy content. Formation of sigma phases are also observed at the rest of the

Failure is in a sense the highway to success, as each discovery of what is false leads us to seek earnestly after what is true- **John Keats**

cross-section (Fig.4(b)). Microstructures at the inner side of the cross-section of ABZ does not reveal any severe carbide network unlike that of Fig.4(a); but some precipitates of carbides can be observed as shown in Fig.5(a). The microstructure at the cross-section of the unused plate is shown in Fig. 5(b) which shows austenitic matrix with stringers of delta ferrite.

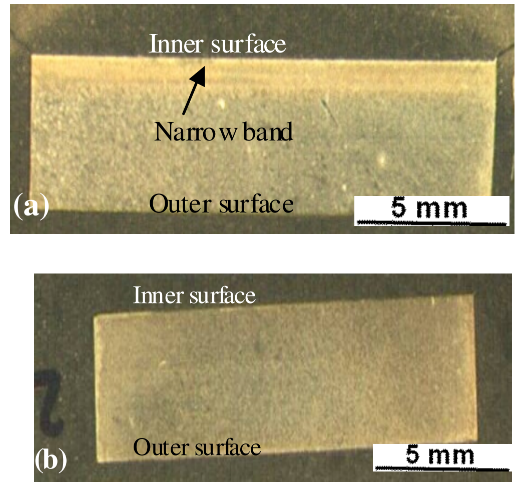


Fig.3 Macro-structure at the cross-section of the inner cover at (a) bulged out zone, and (b) away from the bulged out zone

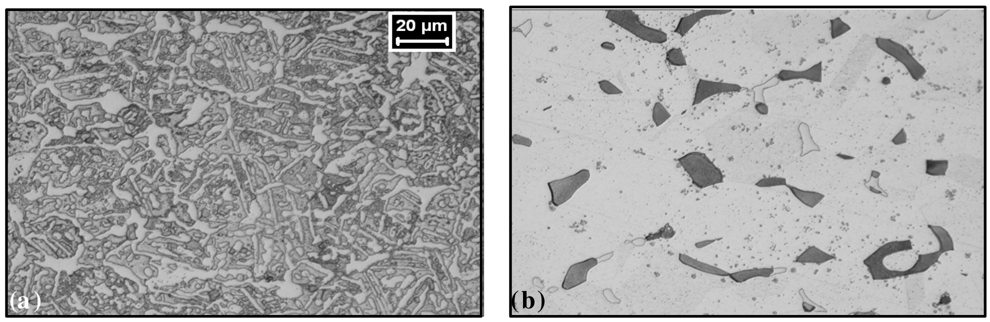


Fig.4 (a) Microstructural examination at the cross-section of the shell: (a) inner side of the specimen from bulged out zone exhibits formation carbide networks, (b) outer side of the specimen shows formation of sigma phases.

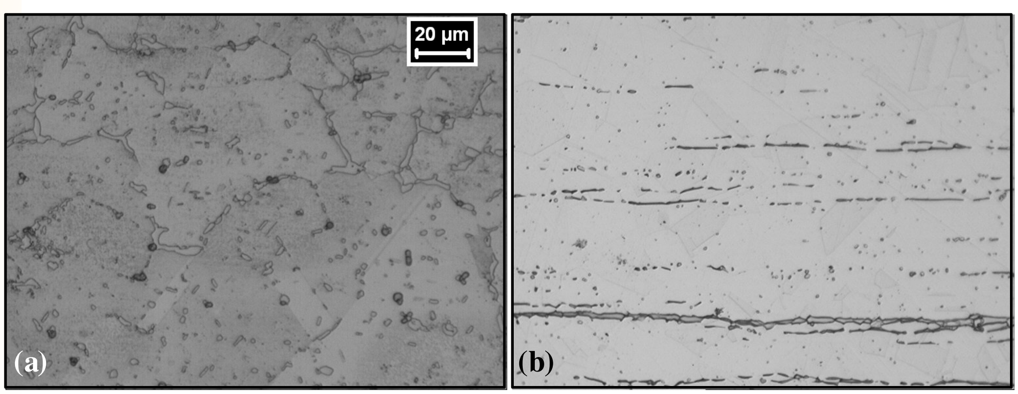


Fig.5 (a) Microstructural examination at the inner side of the specimen away from bulged out zone, (b) Microstructure at the cross-section of an unused plate.

The most important of my discoveries has been suggested to me by my failures. - **Sir Humphrey Davy**

3.3 EDS Analysis

The cross-section of the specimen from BZ was examined under a scanning electron microscope (SEM) operated at an accelerating voltage of 15 kV. Energy Dispersive spectroscopy (EDS) of a few selected areas on the cross-section were carried out as shown in Fig. 6 (a) using the SEM to analyze the microstructure. The EDS analysis at the inner side of the cross-section (BZ) confirms the presence of chromium carbide network; the results of EDS analysis of the network is shown in Fig. 6 (b) and Table 2. The analyses show that the matrix becomes lean in Cr content due to formation of carbide network rich in Cr content. The results of EDS analysis at the outer side of the cross-section have been shown in Fig. 7 and Table 3. The results indicate the formation of sigma phase within the matrix [2-5].

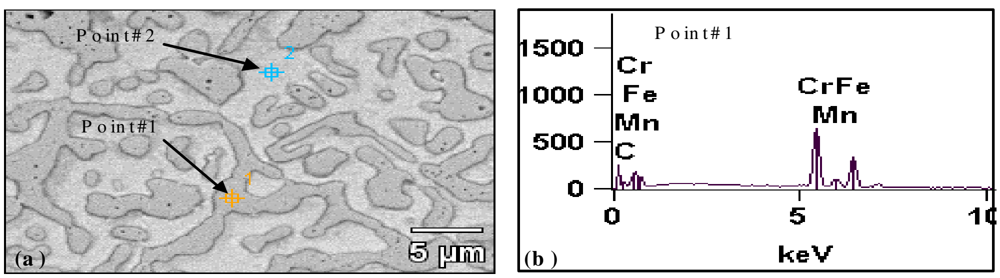


Fig.6 (a) Location of EDS analysis at the inner side of the specimen from bulged put part, (b) Results of EDS analysis confirming the presence of chromium carbide network.

Table2: Results of EDS analysis of inner side of the specimen

Locations	*C*	*Si*	*Cr*	*Mn*	*Fe*	*Ni*
Pt.1 (network)	0.74	–	52.69	1.26	45.29	–
Pt.2 (matrix)	–	1.03	6.53	–	72.19	20.23

Table 3: Results of EDS analysis (wt.%) at the outer side of the specimen

Locations	*Si*	*P*	*S*	*Cr*	*Mn*	*Fe*	*Ni*
Sigma phase							
Pt.1	0.995	0.282	0.407	39.914	1.256	51.232	5.915
Pt.2	0.928	0.254	–	40.693	1.222	51.405	5.497
Pt.3	1.098	0.493	0.518	39.097	1.374	50.958	6.462
Parent metal matrix							
Pt.4	0.667	–	–	17.760	1.248	62.772	13.553
Pt.5	0.577	–	–	18.032	1.655	62.804	12.932
Pt.6	0.633	–	0.164	17.585	1.442	62.594	12.583

3.4 Hardness Profile

Hardness values were measured at the inner and outer side of the cross-section of the specimens from BZ, ABZ, and the unused plate with the help of a Vickers hardness testing machine. The results are summarized in Table 4. The hardness value at the inner side is found to be higher than that of outer side for the specimen from BZ, while the other two specimens exhibit similar hardness values both at the inner and outer side. The micro-hardness profiles were also determined across the thickness by a micro-Vickers hardness testing machine using a load of 25 gm with an indentation duration of 15 s. The micro-hardness profiles are shown in Fig. 8. The micro-hardness profiles show gradual increase in hardness values from outer side to inner side for BZ (i.e., BZ-1 and BZ-2) whereas no such trend is observed for the specimen from ABZ (i.e., ABZ-1 and ABZ-2). The increase in hardness value at the inner side of the bulged zone is due to the formation of excessive carbide network.

Table 4: Hardness values at the cross-sections of the samples

Samples	Surface	Hardness (Hv)
Sample-1 Bulged Zone	Inner	366
	Outer	168
Sample-2 Bulged Zone	Inner	325
	Outer	180
Sample-1 Away from Bulged Zone	Inner	195
	Outer	190
Sample-2 Away from Bulged Zone	Inner	167
	Outer	163

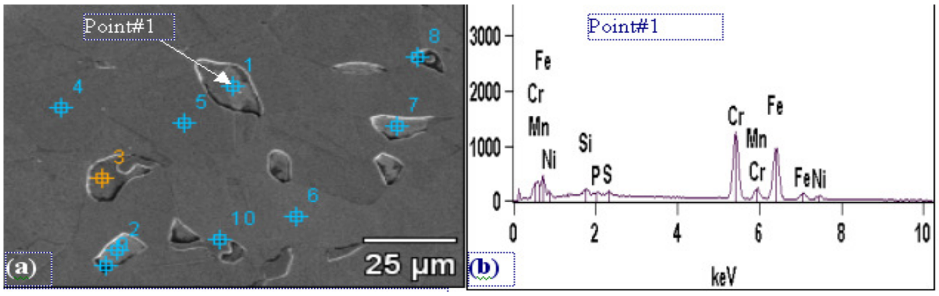


Fig.7 (a) Location of EDS analysis at the outer side of the specimen from bulged zone, (b) Results of EDS analysis shows the formation of sigma phase.

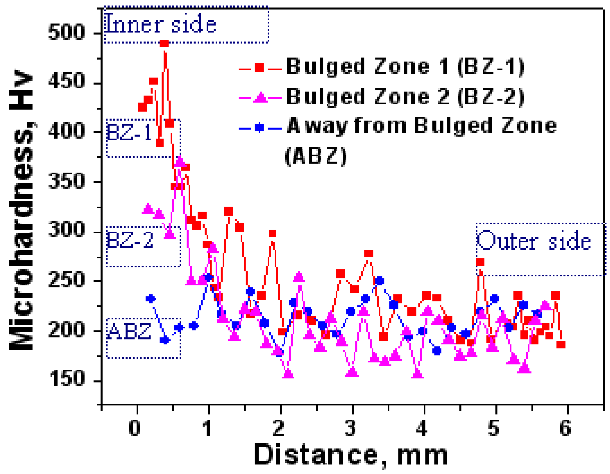


Fig.8: Micro-hardness profiles across the thickness of the bulged out inner cover

4. Discussion

The inner covers of batch annealing furnaces of a cold rolling mill are bulging out near the burner zone within 2 to 3 years of service. Visual observation of the inner covers reveals deposition of carbon at the inner side as shown in Fig.2 (b). The material of the inner cover is found to be AISI 309S grade of austenitic stainless steel. The detail chemical analysis (Table 1) indicates higher amount of carbon content at the inner surface compared to that of outer surface; carburization occurs at the inner side of the bulged zone of the inner cover near the burners from the deposited carbon on it during annealing of the coils. The primary source of carbon deposited on the inner surface is the oil adherent to the coils; carburization takes place at the inner surface of the cover near the burners where the cover temperature is around 900 - 1000°C. This phenomenon is supported by some existing literature [4, 5].

Carburization of stainless steel can occur in carbon monoxide (CO), methane (CH_4), and other hydrocarbons. Carburization can also occur when stainless steels contaminated with oil or grease are annealed without sufficient oxygen to burn off the carbon [4]. This can occur during vacuum or inert gas annealing as well as open air annealing of oily parts with shapes that restrict air access. Hau and Seijas [5] have found carburization at inside surface of TP 347H SS heatertube after 3.6 years in delayed coker service at skin metal temperature varying from 538°C to 766°C because of coke deposition.

Microstructural examination at the cross-section of BZ exhibits formation of severe carbide networks at the inner side as shown in Fig.4 (a). The results of EDS analysis conforms the formation of mainly chromium carbide network as illustrated in Fig.6 (b) and Table 2. Although in AISI 309S, the original carbon content is low (C: 0.08% max.), carburization at the inner surface supplies additional carbon required for the formation of carbides. Carburization leads to the formation of internal carbides thereby degrading other mechanical properties [1, 6]. The measured micro-hardness profile across the thickness of the cover shell shows increase in the hardness values from the outer side to the inner side (Fig.8). At the inner side, the micro-hardness is found to be in the range 400-450 Hv which is in agreement with the report of Hau and Seijas [5] where they have measured the microhardness as high as 450 HV on the carburized layer at inner side of tube.

Formation of sigma phases is also observed at the cross-section as shown in Fig.4 (b). The results of EDS analysis as illustrated in Fig.7 and Table 3 confirm the formation of sigma phases within the matrix; the composition of sigma phase (Cr: 40%, Fe: 51%, bal.: Si, S, P) is shown in Table 3. David et al. [7] have mentioned the composition of sigma phase as Cr: 38%, Fe: 59%, and Ni: 3% while Hau and Seijas [5] have estimated the content of Cr and Fe in sigma phase as 35% and 55%, respectively. Therefore, the composition of sigma phase estimated in the present investigation is found to be similar to those mentioned in the existing literature [5, 7]. Sigma phase is a non-magnetic intermetallic phase composed mainly of iron and chromium which forms in ferritic and austenitic stainless steels during exposure at 560º-980ºC; sigma phase formation is unavoidable in many of the commercial austenitic stainless steels (like Series 300) within the temperature range due to thermodynamic instability, and precipitation of second phase intermetallic precipitates. It causes loss of ductility, toughness and creep properties.

Formation of carbides and sigma

phases make the cover matrix lean in alloy content at the high temperature zone and decreases their creep properties [6] which results in bulging of the inner cover at the bottom part adjacent to burners under self weight.

It is important to note that alloying elements (like Cr) present in the matrix improve the corrosion resistance and high temperature properties. The existing material, AISI 309S, is not very creep resistant at high temperature above 800°C. Formation of alloy carbides due to carburization at inner surface removes the alloying elements from the matrix of cover material and degrades its corrosion resistance and high temperature properties like creep.

5. Conclusion

Analyses of the above results suggest that formation of carbides due to carburization attack make the cover matrix lean in alloy content at the high temperature zone adjacent to burners and decreases its creep properties which results in bulging of the inner cover.

References

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Dr. Sandip Bhattacharyya is a B.E. in Metallurgical Engineering from Bengal Engineering and Science University, Shibpur, Howrah. He joined Tata Steel Ltd in 1997 after completing his PhD in Metallurgical & Materials Engineering from I.I.T., Kharagpur. Presently he is Heading the Scientific Services Department of Tata Steel Ltd. Dr. Bhattacharyya is the recipient of National Scholarship, Govt. of India, CSIR Individual Fellowship, Dr. K. S. Krishnan Fellowship, and Post doctoral Fellowship, Max Planck Institute, Stuttgart, Germany. He is life member of Indian Institute of Metals, Indian Society for Non Destructive Testing, and Indian Society for Engineering Failure Analysis and Vice Chairman, Indian Institute of Metals, Jamshedpur Chapter. He is having 31 papers in international journal and 27 conference presentations. He has filed 7 patents and guided one PhD, one M.Tech and two B.Tech students of IIT Kharagpur.

Mr.Goutam Mukhopadhyay completed Bachelor of Engineering with first class in Metallurgical Engineering from Jadavpur University, West Bengal in 2001. He joined Tata Steel Ltd., Jamshedpur In 2006, he successfully completed the Graduate Aptitude Test in Engineering and joined the Indian Institute of Technology, Kharagpur to pursue Ph.D programme. He has participated in several national and international conferences to present his work, apart from attending a number of workshops and training programmes including one at McMaster University, Canada in 2003. A major part of his work consists of failure analysis of engineering components which has already been published in peer reviewed International Journals.

Registration form

Name of the participant:

1.

2.

Affiliation

Mailing address:

Phone:

Mobile:

Fax:

presenting poster: Yes/No

Email:

DD details (No, date , bank)

Signature

Registration form

Name of the participant:

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Affiliation

Mailing address:

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presenting poster: Yes/No

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Signature

Clinic on Failure Analysis (CFA-2011)

Dec, 22-24, 2011

at

IGCAR, Kalpakkam

Organized by
IGCAR, Kalpakkam
Society for Failure Analysis, Hyd
Indian Institute of Metals, Kalpakkam

Clinic on Failure Analysis
(CFA-2011)
Dec, 22-24, 2011
Organized by
IGCAR, Kalpakkam
Society for Failure Analysis (SFA), Hyderabad
&
Indian Institute of Metals, Kalpakkam

Towards understanding why the structural materials fail, selection of the material, manufacturing route adopted for the component and its service exposure conditions are extremely important for any industry. Thus failure analysis at different levels of building a component- be it the design stage or in-service or end-of-life is an essential element of all successful industrial ventures.

Expert personnel in the area of failure analysis are many who have dealt in a wide spectrum of failures. While experience built by individual experts would form inputs for future endeavors, regular meetings and interactions among the experts and young people help in reducing future failures and thus save time, money and energy. In order to achieve these ends, Society for failure Analysis (SFA) has initiated a wide range of activities, including monthly lectures, meetings, newsletters, conferences and much more.

Currently SFA joins IGCAR, Kalpakkam and IIM Kalpakkam chapter in conducting a 3-day Clinic on Failure Analysis [CFA-2011], which covers an overall view on failure analysis on the first day. Followed by sessions focus on failures specific to industries and materials on the next two days. Further, CFA-2011 plans to involve lectures by experts in the morning session followed by demonstration of failure analysis in the afternoon.

It is our hope that the clinic would provide a stimulating experience to the young minds. It would also give them an opportunity to interact with the experts and peers who would deliver the motivating lectures on the topics like:

- ❖Failure analysis methodology
- ❖Fail-safe design and prediction of life
- ❖Industry-specific failures
- ❖NDT methods for surveillance monitoring of critical components

Clinic is designed for engineering graduates who wish to develop expertise of the failure of materials. Therefore proposed clinic involves participation of the research scholars and young scientists. It is limited to 100 participants drawn from colleges and universities on first cum first served basis. Posters depicting failure analysis work by young participants are welcome for display during the workshop, which may be considered for best poster award. The participants for the workshop have to pay a fee of Rs.1000/- (Rupees One thousand only) by a DD drawn in favour of Clinic on Failure Analysis-2011 payable at Kalpakkam taken from any nationalized bank.

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TORSIONAL FATIGUE FAILURE OF A TOWER CRANE WIRE ROPE

N G Muralidharan, IGCAR, Kalpakkam

INTRODUCTION

Wire rope of a tower crane used in a construction site suddenly failed at a height of approx 5 meters while lifting a bucket containing a load of less than a tonne. Detailed failure analysis was carried out to find out the root cause of the failure.

The failed rope of the crane is of 16 mm diameter non rotating type 18 X 7 construction. However, the crane was originally supplied with rotation resistant type, with 16 mm diameter rope of 24 X 7 constructions. Later on the rope was changed to 18 X 7. The crane was operated for almost 1050 hrs till failure.

Figures 1 shows the tower crane and figure 2 shows the failure location of the rope along with the crane and close up of view of the failed rope. Fig.3 show the c/s of actual failed rope and Fig.4 (a) & (b) show the decoloration in the wires. Fig.5 depicts caging of rope.

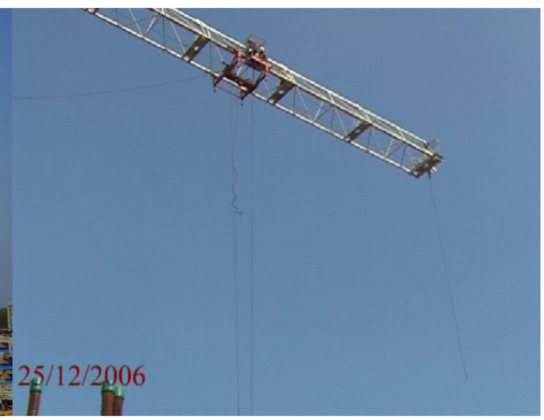
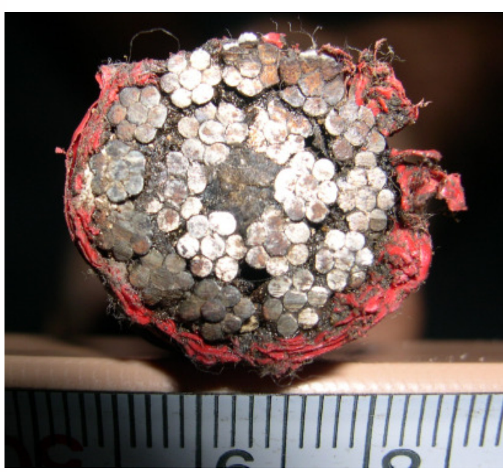


FIG 1 VIEW OF THE TOWER CRANE **FIG 2** FAILURE LOCATION OF ROPE



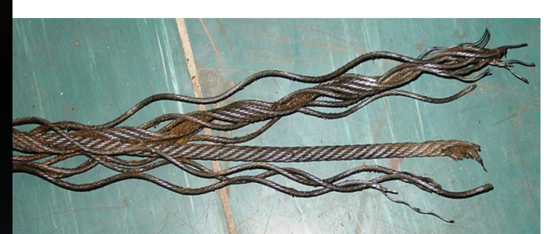


Fig 3 FAILED ROPE 18 X 7 **Fig 4 (a)** END OF THE FAILED ROPE

Fig.4 (b) ROPE SHOWING DECOLOURISING
DUE TO FRICTION HEATING

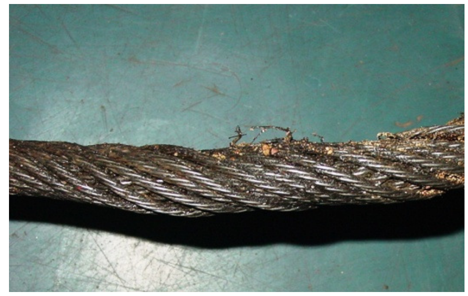


Fig 5 CAGING (UNWINDING) ON THE ROPE

STEREO MICROSCOPIC EXAMINATION

Stereomicroscopic examination of individual wires of the failed rope revealed heavy surface damage to the wire rope and fracture ends show typical torsional failure mode (Figs 6 a & b).

TENSILE TEST

Tensile tests were carried out on individual wires taken from both the failed wire rope pieces and fresh rope (Table I). The test results showed that they meet the mechanical properties as per the standard specifications.

Table I
Mechanical Properties of the wires

Sample ID	YS (MPa)	UTS (MPa)
Wire rope Failed	1710	2354 / 2178
Wire rope Fresh	1625	2052 / 2114

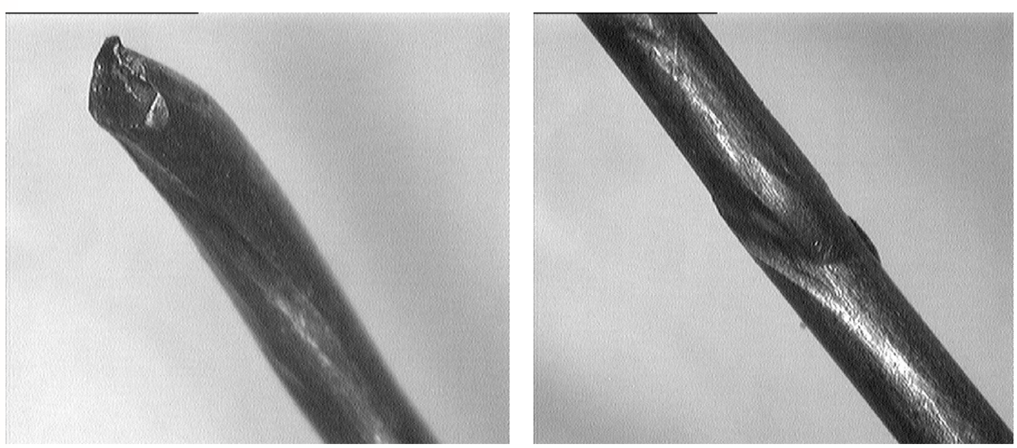


Fig 6 (a) FRACTURE ENDS SHOWING TYPICAL TORSIONAL FAILURE MODE AND (b) HEAVY SURFACE DAMAGE EXHIBITING TORSIONAL LOADING

CHEMICAL ANALYSIS

Chemical analysis was carried out on samples and it was in agreement as per IS 228. (Table II). It is observed that while the specified carbon content is on the hypoeutectoid side of the Fe-C diagram, the carbon content of the constituting wires of the rope is hypereutectoid in nature. In order to confirm this, microstructural examination was carried out in detail which is discussed in the following paragraphs.

OPTICAL METALLOGRAPHY

Optical metallographic examinations were carried out on the cross section of the failed rope. Figure 7 (a) shows the cross section of the seven wires of a strand. Figure 7 (b) shows the cross section of the one of the seven wires at higher magnification that reveals heavy mechanical damage to the wire (the wire is not a perfect circle) and presence of peripheral radial micro cracks was also seen (arrow). The micro radial cracks are probably due to fatigue loading. In order to further explore the origin of the crack, metallographic etching was carried out and following section discusses the results on the microstructure of the edge as well as the core of the wire, which has failed by torsion.

Table II. Chemical analysis of the rope shown in comparison with specification

Composition	Chemical composition (wt%)	
Element	Specified range as per IS 228	Failed Rope
C	0.35 –1.0	0.86
Si	0.1 -0.3	0.14
Mn	0.3 – 0.9	2.28
S	0.02-0.05	0.013
P	0.02-0.05	0.07
Cr	0.05-0.2	0.09
Ni	0.05-0.2	0.12
P+S(Max)	0.08	0.083

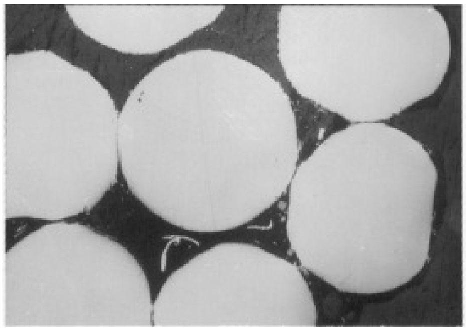


FIG 7 (A) CROSS SECTION OF THE SEVEN WIRES

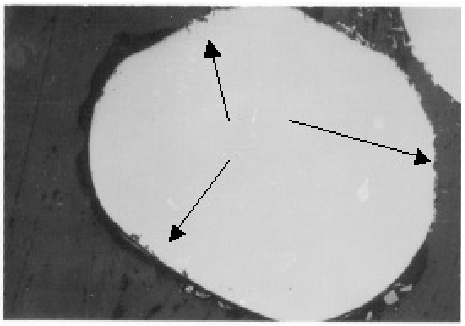


FIG 7 (B) CROSS SECTION ONE OF THE SEVEN WIRES

METALLOGRAPHIC STUDIES

SEM studies were carried out on the polished and etched cross section of the individual wires as well as from all the fracture surfaces of the wires. The general microstructure of the wire shows pearlite with cementite (Fig 8) indicating that the carbon content is more than 0.8%. Figures 9 and 10 show the microstructure of the material at region close to the fractured surface at different magnifications. White areas are pearlite and dark areas are cementite. Decarburized area was observed near the failed zones as can be seen from reduction in microhardness (Fig 11), which could be due to frictional over heating. In order to confirm our findings, microhardness measurements around the edge and the core were carried out.

MICRO HARDNESS MEASUREMENT

Microhardness measurements were taken on the single wire strand of the rope cross section for all the ropes. Hardness values were also taken on the polished surface at the failed region. It was found that the average hardness of all the wires was around 650 VHN. On the other hand, in the failed region, the hardness was around 572 VHN near the outer region and 882 VHN in the interior region, confirming decarburised layers.

Failed rope	**612, 657 VHN**
Near failed Region	**Centre: 882 VHN** **Edge: 572VHN**

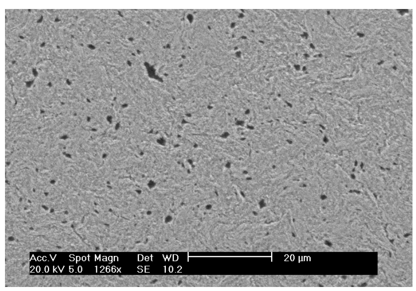


FIG 8. CROSS SECTION OF WIRE THE FAILED AREA

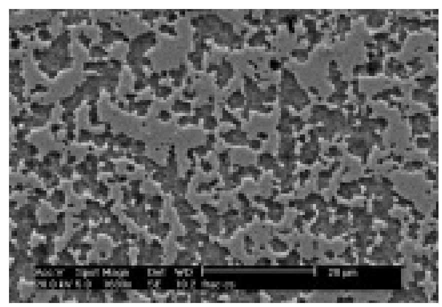


Fig 9. FRACTURE CROSS AWAYFROM SECTION CLOSE TOFAILEDREGION

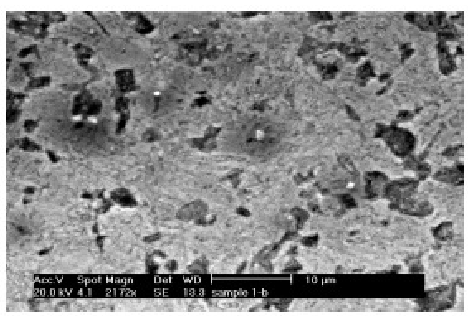


Fig 10. PARTICLES OF CEMENTITE IN THE MATRIX OF PEARLITE

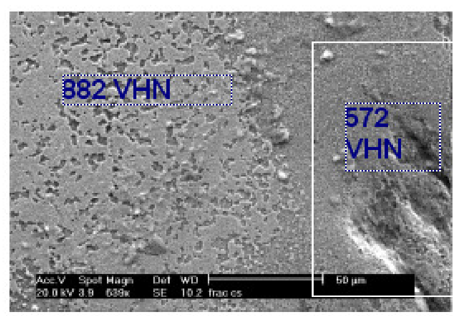


Fig 11. CROSS SECTION CLOSE TO THE FAILED REGION SHOWS DECARBURISED AREA

Fractographic examination

Fractographic examination carried out on several failed sections of the wires revealed that the wires failed by torsional fatigue. The initiation of the fatigue failures has taken place from the outer surface of the wires starting from inclusion sites and smooth propagation across the cross section of the wire and final failure at the outer surface (Fig12). Typical torsional fatigue failure and EDAX analysis shows the presence of Si as inclusion at the crack initiation site (Fig 13)

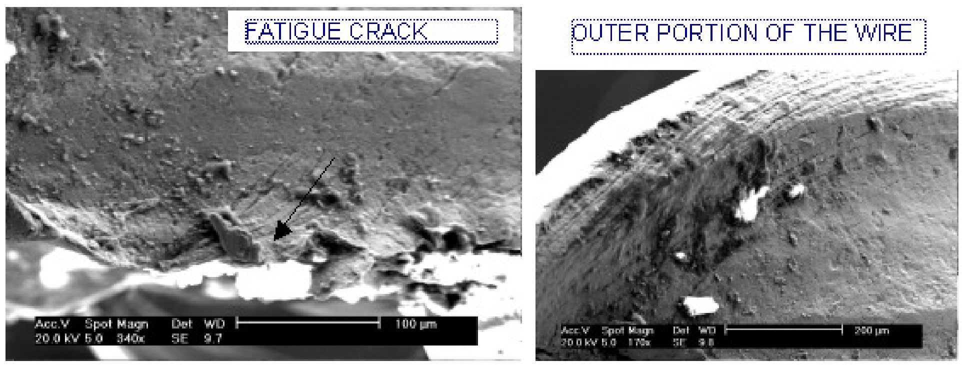


FIG 12 SHOWS THE TYPICAL FATIGUE CRACK ORIGIN AND SMOOTH PROPAGATION AND FINAL FAILURE

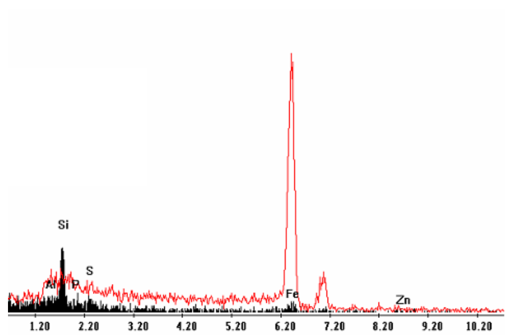


FIG.13 EDX SPECTRA CORRESPONDING TO AN INCLUSION SUGGESTS SILICON RICH NATURE. THE MATRIX SPECTRUM SHOWN IN RED FOR COMPARISON.

SUMMARY OF THE INVESTIGATIONS

Visual examination revealed extensive deformation of the wire strands at the failed regions.
Configuration of the wire rope used is 18x7 (instead of 24x7 as recommended by the supplier) which is less flexible.
Caging was observed in two places indicating less flexibility of the rope and twisting of rope may be assisted due to malfunctioning of the swivel attachment at the jib end.
Stereomicroscopic examination shows heavy surface damage to the wire near the failed ends and fracture ends show torsional failure. Chemical analysis of the wire indicated within acceptable range as per specifications.
Mechanical properties are in line with specifications.
General microstructure of the wire shows fully pearlite + cementite.

Area near to the failed edge showed evidence of overheating as the pearlite got re-dissolved while cementite remained intact. [Ref.1]. Microhardness near the failed region was 882 VHN (inner) and 572 VHN (outer) may be due to overheating and decarburization whereas the microhardness of the rope is in the range of 640 - 690 VHN. Optical metallographic examination revealed a number of radial micro cracks at the circumference of the wire. SEM studies showed evidence of failure of rope is due to torsional fatigue failure.

CONCLUSION

The main cause of the failure is high torsional fatigue experienced by the rope during operation. The less flexibility of the wire rope due to 18 X 7 construction and the malfunctioning of swivel attachment have resulted in early fatigue failure of the wires.

After the failure of a few strands of the wire in addition to caging of the rope, entanglement of the failed ends on the pulley could have resulted in severe damage to the wires and over heating of the wires due to friction.

RECOMMENDATION

- Use of 24 X 7 wire rope will give more flexibility and prevent caging and consequently less damage to the wire This would also help in high fatigue life of the rope
- Periodic visual inspection of the wire for caging and ensuring proper functioning of the swivel end attachment, which will avoid such failures in future.

References:

1) E.C.Rollason: Metallurgy for engineers- Edward Arnold, London, The U.K., 1949, p182

Author wishes to acknowledge all his colleagues who had contributed in the various failure investigations over the last three decades.

Sri.N.G.Muralidharan, a B.Sc. graduate from Madras University joined DAE in 1972. Having acquired experience in metallurgy, he successfully completed Associate membership of Institution of Engineers (metallurgy) from institution of engineers (India) in 1978. His vast experience over the last thirty five years encompass the following:

- fuel fabrication by powder metallurgy route
- Post irradiation examination of fuel and structural materials

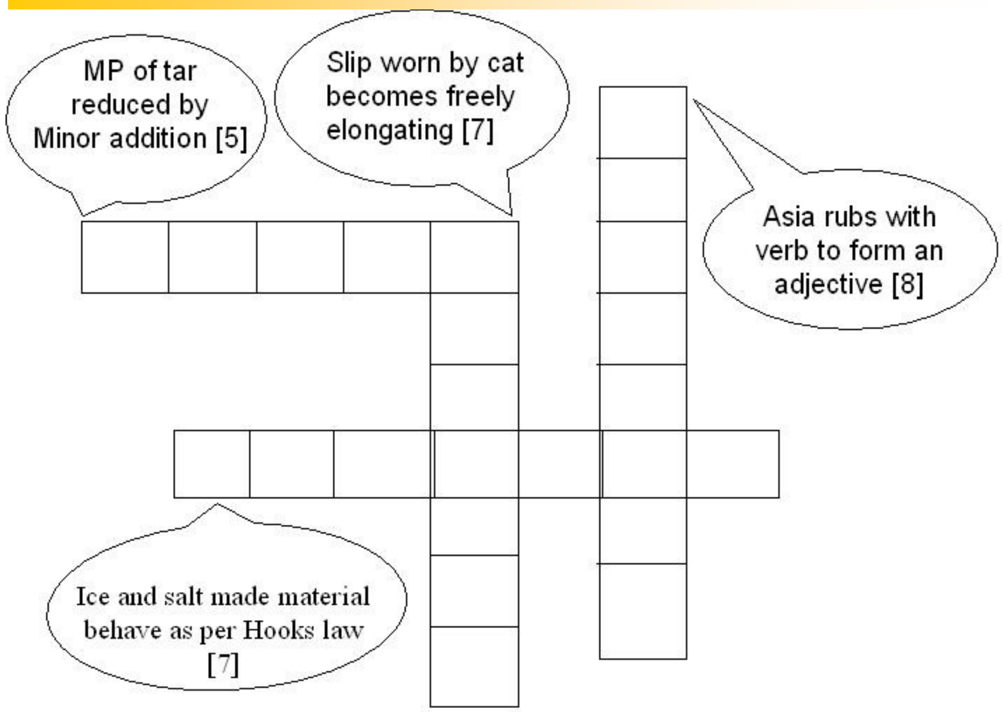
He has developed expertise in the fields of metallurgy like failure analysis, metallography and mechanical testing
He has received the following awards:

- Nucor award from IIW (1994)
- IT Mirchandani award from IIW (1991)
- best metallography awards from IIM (1989,1991,1996)
- best technical paper awards from IIM, INS and IIW

He has more than 70 papers in conference, seminar, workshop and journals.
He is a member of

- Institution of engineers (India)
- Indian institute of metals
- Indian society for non-destructive testing

Cross word puzzle on failure analysis terminology



See last page for answers:

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Details of the inaugural function in next issue

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Events in the pipeline

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 Yildiz Technical University in Istanbul, Turkey. The 9th International Fracture Conference is again organized by Yýldýz Technical University, Ýstanbul.

The aim of the conference is to present a scientiýc 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

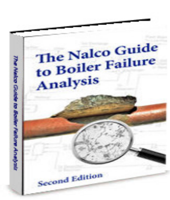
- Brittle and ductile fracture
- Fracture behavior in static and dynamic loading
- Fracture mechanics
- Crack nucleation and propagation
- Fatigue, creep, fracture behavior of metallic, ceramic, polymeric, composite materials
- Fatigue, creep, fracture behavior of biomedical and nano materials
- Residual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

The 15th European Conference on Composite Materials takes place from 24th to 28th June 2012 in Venice, Italy. Please visit http://www.eccm15.org/ for more information

Oral and poster abstracts are now invited and should be submitted using the online abstract submission system.

The abstract deadline for oral and poster submissions is: **Friday 17th February 2012**

Books



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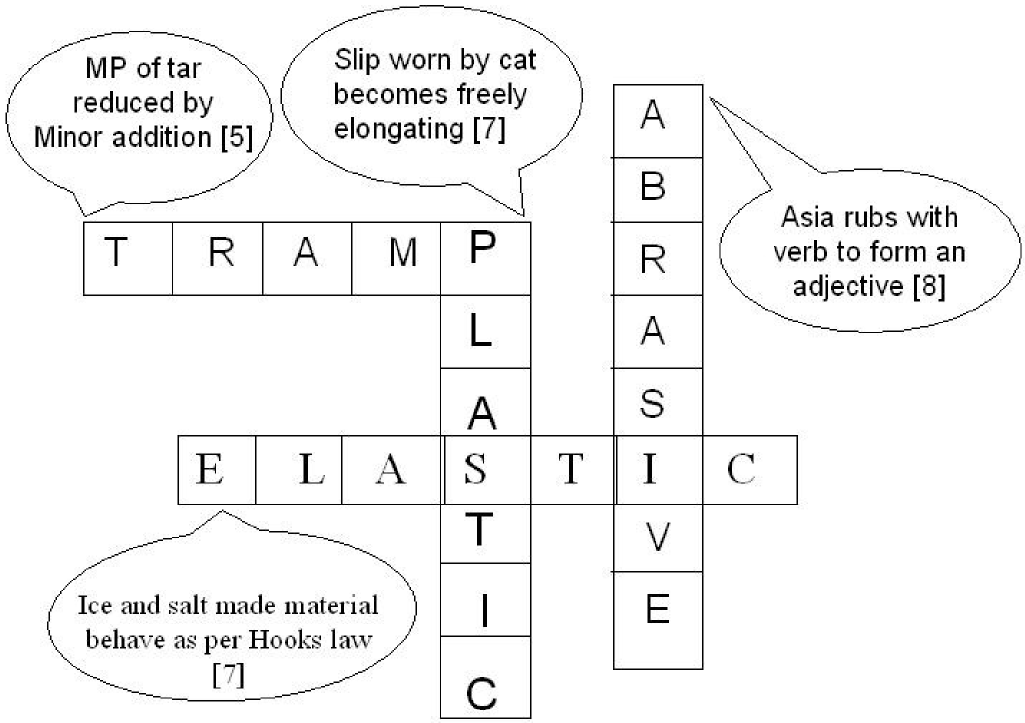
Answers to the crossword:



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