



Image

The Technical Bulletin of
Indian Society for Non - Destructive Testing
Thiruvananthapuram Chapter

www.isnttvm.org



ISNT Trivandrum chapter won the prestigious “ISNT-PULSECHO” BEST CHAPTER AWARD for the year 2016 and it was presented at the inaugural function of NDE 2016-National Conference and International Exhibition held at Al Saj Convention Centre, Trivandrum from 15-17, Dec 2016. This is third time our chapter is receiving this honor after 2002 & 2012. We thank all chapter members who made this possible.



The chapter’s former chairman and senior member **Shri S. Saratchandran**, VSSC was awarded the “Honorary Fellow” of ISNT for the year 2016. This is in recognition of his significant contributions in the field of NDT in space and to the society.



ISNT-NDTS award for “Excellence in contribution to NDT Systems innovation & development-National NDT Award” was awarded to **Shri Cherian Thomas** for his contribution in the establishment of Neutron Radiography facility at VSSC.



From Chairman's Desk...

Dear Members,

First of all let me extend all ISNT fellow members happy, healthy and eventful New Year.

With all your cooperation, we had a successful and eventful year 2016. NDE 2016 was a grand success earning appreciation from all levels of participants. Team NDE 2016 deserves appreciation for the hard work put forth for almost one year. My heartfelt gratitude and appreciations to all of you. I expect similar spirited team effort in all future endeavours as well.

Our chapter received 'The Best Chapter Award' for the third time. I compliment and congratulate all the chapter members for this great achievement. Shri S Saratchandran, former chairman received "Honorary fellow" of ISNT for the year 2016 & Shri Cherian Thomas received the award in the category of "Excellence in contribution to NDT Systems innovation & development". I congratulate both of them and thank them for the contributions to the society. It is heartening to note that the contributions of our chapter members are being recognized at national level and wish more accolades to our members in the years ahead.

The fact that we could also arrange regular workshops at colleges, young engineers' forum lectures & sponsored technical presentations as usual shows the commitment of our team to ISNT activities.

NDE fetched us revenue also which will help us to continue with various technical activities of our chapter. Another significant gain we had due to NDE 2016 was the addition of members to our chapter. We could add close to 150 life members during the pre & post NDE 2016 period. I sincerely appreciate all area coordinators for the same. At the time of writing this report, we have about 490 members and the target of 500 will be reached very soon with

your sustained efforts. I am personally impressed to have achieved this magic mark of 500 and dedicate this achievement to our team members.

Our long term wish of industrial visit to Koodankulam Nuclear Power Plant has materialised and the 1st batch visited KNPP on 25.03.17. The response was overwhelming and, since we are allowed to take only a maximum of 50 in the first batch, arrangements are being made to take the second batch by May 2017.

After the hectic schedule of NDE 2016, our regular activities have resumed and two important lectures were organised by Young Engineers' forum with active participation from our members.

As the bulk of our new members are very vibrant youngsters, our expectations are very high and I wish all of them a very fruitful association and an ocean of opportunities with ISNT. I wish all of them will actively participate in all our activities and contribute to the technical knowledge dissemination and take the chapter to greater heights.

A new team for the editorial board of *IMAGE*, under the guidance of our Vice Chairman Shri KR Mohan Ananthanarayanan, has been constituted and this is the first issue brought out by them. I thank and compliment Shri Binu P. Thomas, former editor, & Shri Binu B, who is continuing in the new team also, for their excellent work in Image Editorial Board for the past two years. I wish all the very best for the new team and it is my desire to see uninterrupted publication of *IMAGE* by this team.

With best wishes..

G. Levin
Chairman,
Trivandrum Chapter



Secretary's Report-NDE 2016

NDE 2016, 26th National Seminar & International Exhibition was conducted by ISNT Thiruvananthapuram Chapter during 15-17 December, 2016 at AISaj Convention Centre, Thiruvananthapuram. Highlights of the event are given below.

Pre-Conference Tutorial

As a prelude to the main event, preconference tutorial was arranged on three topics during 13 & 14 December, 2016 at HRDD seminar halls of Vikram Sarabhai Space Centre (VSSC). It was inaugurated by Shri S. Pandian, Associate Director, VSSC. A total of 47 delegates participated in the preconference tutorials conducted on three topics as below;

1. Digital NDE- Principles & Practices
2. Corrosion- Detection, Measurement & Evaluation
3. Advanced NDE for Propellants & Composites

All the lectures were handled by experienced faculty from ISRO & other leading private and Government organizations like BARC, IGCAR, DRDO, GE, Olympus etc. The program was concluded on 14.12.2016 with valedictory function attended by Shri B. Jayakumar, Project Director, PSLV, VSSC. Participation certificates were distributed to all the participants.



Shri S. Pandian, Associate Director, VSSC inaugurating the Pre-conference tutorials held at ATF, VSSC

Inauguration of NDE 2016

The seminar was inaugurated in a grand function held at Al SAJ Convention Center at 9:00 AM on 15.12.2016. The function was presided over by Shri DJ Varde, President ISNT. Shri G Levin, Chairman, Organising Committee welcomed the gathering and Shri S Saratchandran, Co-Chairman, Organising Committee introduced the theme of the seminar. Shri A.S Kiran Kumar, Chairman, ISRO/Secretary, Department of Space inaugurated the seminar through live video address from NRSC, Hyderabad. Keynote address was delivered by Dr. K. Sivan, Director, VSSC. Shri M.C. Dathan, Scientific Advisor to Chief Minister of Kerala & Former Director, VSSC released the souvenir & proceedings and offered felicitations. Shri Rajul R Parikh, Honorary Secretary offered felicitations. The NDT national awards 2016 were distributed at the function. Shri K R Mohan Ananthanarayanan, Convener, NDE 2016 proposed vote of thanks.



Shri A.S Kiran Kumar, Chairman, ISRO / Secretary, Department of Space inaugurating the seminar through live video address from NRSC, Hyderabad.



Dr. K. Sivan, Director, VSSC delivering the keynote address

International Exhibition

The exhibition was inaugurated by Dr. K. Sivan, Director, VSSC. A total of 46 leading players in the field of NDT equipments and services showcased their products & services. The following were the sponsors of the event.

Type	Organization
Principal	GE Oil & Gas Digital Solutions India
Platinum	OLYMPUS
Silver	Blue Star E & E Limited, Chennai
Bronze	VJ Imaging Technologies Pvt. Ltd.
	LPS Industrial Supplies Pvt Ltd.
	Varian

All leading international & domestic players in NDE field participated in the exhibition, which was well attended by all participants on all three days of the seminar. An exclusive presentation by the sponsors was arranged on 1st day and all the sponsors were given opportunity to brief about their products and services.

Technical lectures

Memorial & Plenary Lectures (First Day)

A K Rao memorial lecture by Dr. P. Kalyanasundaram, Former Director (FRTG), IGCAR & VS Jain memorial lecture by Prof. Krishnan Balasubramanian, IIT Madras were arranged in the forenoon session.

Three plenary lectures by Dr. B. Venkatraman, Director HESG, IGCAR; Shri RS Sundar, Site Director & Dr. Suresh Babu, Chief Engineer (QA), Koodankulam Nuclear Power Plant; Dr. Prabhat Munshi, IIT Kanpur were arranged in the afternoon session

Parallel Technical Sessions (2nd And 3rd Days)

Parallel sessions as below covering all techniques of NDT, advancements, various applications, training and safety were arranged. Each session was started with an invited lecture by an eminent expert in the relevant topic of the session.

No. of parallel sessions : 4

Total no. of sessions : 24

Oral Presentation

Contributory papers : 132

Invited lectures : 22

All sessions were well attended by delegates and other participants.

Poster Sessions

Poster session was conducted on both 2nd and 3rd days and a total of 50 posters were presented by the delegates.

Souvenir & Proceedings

A souvenir of the event was released at the inaugural function and distributed to all delegates. The souvenir contains all abstracts of invited & contributory papers including posters. In addition to the complimentary advertisements of sponsors & exhibitions, it also had ten paid advertisements from various companies. Along with the delegate kit, a hand book of program details and CD containing full papers were also distributed.

Delegate Registration

Paid delegates : 416 nos.
Sponsored delegates : 115 nos.

AGM of ISNT

AGM was conducted on 2nd day evening at main hall of Al Saj Convention Centre. More than 100 members participated and made it a grand success with lively interactions.

Valedictory Function (17.12.16)

Prof. Dr. Kuncheria P. Isaac, Vice Chancellor, APJ Abdul Kalam Technological University, Kerala was the Chief Guest of the function. He distributed following awards at the function to the winners;

1. Best oral presentation
2. Best poster presentation
3. Best exhibitor

Both President & Hon. Secretary, ISNT spoke on the occasion. Delegates also gave feedback on the occasion. The event concluded with a photography session of all members of Team NDE 2016.

Cultural Program



On first day, a fascinating fusion dance program was performed by artists from Kerala Kalamandalam, Thrissur. They performed classical dance forms of India viz. Bharathanatyam, Kuchupudi, Mohiniyattam, Kathakali etc. along with classical music. The evening was well enjoyed by all participants.

On second day, an exciting music program was performed by Digital Voice Group with popular singers from various music contests. This was arranged at KTDC Hotel Samudra, Kovalam, a popular international tourist destination. All guests enjoyed the evening near the beautiful beach of Kovalam.



Members of ISNT Trivandrum Chapter, who led the team to the remarkable success of NDE-2016

New Members Who Joined the ISNT Trivandrum Family

Sl. No.	Name	Type of member	Organization
1	Krishnakumar G.	Life Member	VSSC
2	Jagannathan G.	Life Member	VSSC
3	Benny Peter	Life Member	LPSC
4	Shailesh Kumar Singh	Life Member	LPSC
5	Harikrishnan R.	Life Member	VSSC
6	Suresh R.	Life Member	VSSC
7	NelloriDileep Kumar	Life Member	LPSC
8	VarthaVenkateswarlu	Life Member	LPSC
9	Thomas John M	Life Member	VSSC
10	Ajit Kumar	Life Member	LPSC
11	Manu Sharma	Life Member	VSSC
12	Abraham varghese	Life Member	VSSC
13	VasudevaShenoi.S	Life Member	VSSC
14	Babu R.	Life Member	LPSC
15	Sebastian PC	Life Member	VSSC
16	Arun Chand C.V	Life Member	VSSC
17	Gopakumar M	Life Member	VSSC
18	Sureshkumar P.S.	Life Member	LPSC
19	Murugesan N.	Life Member	IPRC
20	Sudhanshu Chand	Life Member	IPRC
21	Surya Prakash Singh	Life Member	IPRC
22	Kamesh Guru G.	Life Member	IPRC
23	Joseph K.A	Life Member	LPSC
24	Elamurugu S.	Life Member	VSSC
25	Abhishek Kumar	Life Member	VSSC
26	Amitabh Kumar Amit	Life Member	VSSC
27	AchutanandaParhi Dr.	Life Member	VSSC
28	AnilkumarPalengara	Life Member	VSSC
29	Dennis A	Life Member	VSSC
30	Shipudass C D	Life Member	VSSC
31	Sunil K T	Life Member	LPSC
32	Ramesh G	Life Member	VSSC
33	Vinod K G	Life Member	VSSC
34	Damodaran P	Life Member	VSSC
35	Edwin Shibi V	Life Member	VSSC
36	Roy Joseph	Life Member	VSSC
37	Vijayan S	Life Member	VSSC
38	Vasudevan R	Life Member	LPSC
39	Rekha K R	Life Member	LPSC
40	KodatiSrinivas	Life Member	LPSC
41	Vinayaravi R	Life Member	LPSC
42	Jaiganesh A	Life Member	VSSC
43	AravindJithin A J	Life Member	VSSC
44	SalilKanjJalan	Life Member	VSSC
45	Nijesh R.	Life Member	VSSC

Sl. No.	Name	Type of member	Organization
46	Ravibabu Mulaveesala Dr.	Life Member	IIT, Ropar
47	Ghali Venkata Subbarao Dr.	Life Member	K.L. University
48	Padmakumar Nair	Life Member	Individual
49	JayanBabu P	Life Member	VSSC
50	Sajeev S	Life Member	VSSC
51	KiranAcharya	Life Member	VSSC
52	Bibin C T	Life Member	VSSC
53	Shais K Parameshwar	Life Member	VSSC
54	Baburaj K R	Life Member	VSSC
55	Rajesh Anand	Life Member	VSSC
56	Saravanan R	Life Member	VSSC
57	Sriniwas Panda	Life Member	VSSC
58	Arun Krishnan	Life Member	VSSC
59	Jayachandran R	Life Member	VSSC
60	SanthoshBabu	Life Member	VSSC
61	Sanjeev Kumar	Life Member	VSSC
62	Soumit Kumar Biswal	Life Member	VSSC
63	Nagarajan K	Life Member	VSSC
64	Ramesh V	Life Member	VSSC
65	Somanathan S	Life Member	VSSC
66	Arun Raj	Life Member	VSSC
67	SubhashBabu C	Life Member	VSSC
68	Krishnadasan CK	Life Member	VSSC
69	Ramasamy S	Life Member	VSSC
70	Ravikannan S	Life Member	VSSC
71	Kishore KGK	Life Member	VSSC
72	Abraham K. Kurian	Life Member	VSSC
73	Sreekumar PK	Life Member	VSSC
74	Muraleedharan K	Life Member	VSSC
75	Ranjith Kumar Reddy G	Life Member	VSSC
76	Joby V Thomas	Life Member	LPSC
77	Antoney P.L.	Life Member	VSSC
78	John Paul M.A.	Life Member	VSSC
79	Shalu M.S.	Life Member	VSSC
80	Santhosh Kumar AG	Life Member	VSSC
81	AkshayRanjanPathak	Life Member	VSSC
82	Jhon Paul	Life Member	VSSC
83	Jithin G. Mathew	Life Member	VSSC
84	Krishnakumar G.	Life Member	Bright Vac Technologies
85	Aneesh G.T.	Life Member	VSSC
86	Pradeep P.I.	Life Member	VSSC
87	Madheswaran G	Life Member	VSSC
88	Sreejith M Dr.	Life Member	VSSC

Sl. No.	Name	Type of member	Organization
89	Guruvayurappan SBM	Life Member	VSSC
90	Shanmugam V	Life Member	Inkaar Instruments
91	Karthikeyan MK	Life Member	VSSC
92	Srinath J	Life Member	VSSC
93	Ajayakumar MS	Life Member	VSSC
94	TiriveedhiHemanth Gupta	Life Member	VSSC
95	Chakravarthy P	Life Member	IIST
96	Ravi V Dr.	Life Member	IIST
97	ShyamLal	Life Member	VSSC
98	Gaurav Kumar	Life Member	VSSC
99	AnurupGuha	Life Member	IIST
100	Bijudas CR Dr.	Life Member	IIST
101	Divya N.	Life Member	VSSC
102	Asha LR	Life Member	VSSC
103	Saritha S.N.	Life Member	VSSC
104	Manikuttan C	Life Member	VSSC
105	Ravi S.	Life Member	VSSC
106	Jayarajan EV	Life Member	VSSC
107	Subramaniam K	Life Member	VSSC
108	Vijayendra Singh	Life Member	VSSC
109	Manish Verma	Life Member	VSSC
110	Amal Jyothis V	Life Member	VSSC
111	Kalyanaraman R.	Life Member	VSSC
112	Sandeepkumar Sharma	Life Member	VSSC
113	Ajailal SS	Life Member	VSSC
114	SonaliGyan	Life Member	VSSC
115	Dinesh S.B.	Life Member	LPSC
116	Amith A	Life Member	VSSC Apprentice

Sl. No.	Name	Type of member	Organization
117	Ravi V	Life Member	LPSC
118	Varadharajan S	Life Member	LPSC
119	Anilkumar A.K. Dr.	Life Member	VSSC
120	Ravinder Singh	Life Member	VSSC
121	Shanmuganathan D	Life Member	VSSC
122	Venkateswaran T	Life Member	VSSC
123	Yashida Nadir Dr.	Life Member	CET
124	Bindhu KR Dr.	Life Member	CET
125	Vandana RK	Life Member	CET
126	Sasi N.	Life Member	CET
127	ManasMaralShreshtha	Life Member	VSSC
128	Vincent Xavier	Life Member	VSSC
129	PravinMuneshwar	Life Member	VSSC
130	Hani V. Tom	Corporate Member	Torque Engineering Consultants, Kochi
131	Ravikanth S	Life Member	VSSC
132	Chandran P	Life Member	VSSC
133	Sunil S	Life Member	LPSC
134	Naresh Kumar K	Life Member	VSSC
135	Chenna Krishna S	Life Member	VSSC
136	Byju K.K.	Life Member	VSSC
137	Satheesh P.K.	Life Member	VSSC
138	Vijeshkumar M	Life Member	VSSC
139	Vinokumar T	Life Member	VSSC
140	Syamkumar S.R.	Life Member	VSSC
141	Ramlet U	Life Member	VSSC
142	Roy MP	Life Member	VSSC
143	Satish Kumar Singh	Life Member	VSSC

During the period from October 2016 to March 2017, the chapter could add maximum possible members from all areas. This adds glory to the remarkable success of NDE 2016 held at Trivandrum, which have attracted youth from various sectors to join the Society and contribute in its success and day to day activities.

Technical talk arranged by Young Engineers' forum of ISNT

Two technical talks were arranged on 16.03.17 at Hotel Pankaj, Trivandrum under the aegis of Young Engineers' Forum.

The talks were

1. Flux bounded TIG Welding

Shri P. Chakravarthy, Associate Professor, IIST delivered a lecture on "Flux bounded TIG Welding"



Shri P Chakravarthy delivering the lecture.



Shri G Levin, Chairman, ISNT Trivandrum Chapter, handing over the memento to Shri P Chakravarthy

2. Structural Health Monitoring

Shri C R Bijudas, Assistant Professor, IIST delivered a lecture on "Structural Health Monitoring".



Shri C R Bijudas delivering the lecture



Shri Annamala Pillai handing over the memento to Shri C R Bijudas

Both the lectures were a grand success and well received with useful interactions. Around 75 members participated in the program. Shri A. Shanmugavel, Secretary, ISNT Trivandrum Chapter, proposed the vote of thanks.

Workshop at College of Engineering, Trivandrum

A two day Workshop (including lectures and practical demonstrations) on NDE was conducted at College of Engineering, Trivandrum on 18.01.2017 & 19.01.2017. Faculty from ISNT Thiruvananthapuram Chapter delivered lectures at the program attended by the faculty of Civil & Mechanical engineering disciplines of Kerala University.

Our members presented 6 lectures on overview of NDT, various NDT techniques and applications.



Shri Arumugam delivering the lecture on Ultrasonics



Shri Sridhar S delivering lecture on Thermography

Practical sessions were also arranged on Phased Array Ultrasonics, DPT, RT, Acousto Ultrasonics & holography by our members.



Shri Nitesh N performing Phased Array Ultrasonic inspection demo.



Shri Shekhar Nataraj demonstrating Acousto Ultrasonic Technique.

Executive Committee Meetings

During this period, one EC meeting and closure meeting of NDE 2016 were arranged. Various activities were discussed and finalized during EC meeting. After the hectic

schedule of NDE 2016, resumption of all regular activities is given priority. Accordingly it was decided to arrange Young Engineers' Forum lectures, Koodankulam visit, *IMAGE* release etc.

Industrial visit to Nuclear Power Corporation of India Ltd, Koodankulam, Tamil Nadu

A one day industrial visit to NPCIL, Koodankulam was arranged on 25.03.2017 for the members of ISNT Trivandrum Chapter. The chapter received an overwhelming response from the members and a total of more than 100 members registered for the visit. Since only 50 members could be permitted for entry at a time, it was decided to carry

out visit in two trips on first come first serve basis. The first trip consisted of 47 members. KNPP arranged presentations about the plant, field visit (outside reactor), simulator room visit and gallery. The visit was a successful and useful one for chapter members.

Next visit is planned by the end of May, 2017.



Best technical paper award in the NDE-2017 National Conference was given to Shri Swaminathan Annamalai, Nanyang Technical University, Singapore. The paper titled “Residual Stress Profiling of Sub-surface Treated Nickel-Based Super-alloy using Electromagnetic NDE Method” won the award. The paper mentions non-destructive residual stress measurement using eddy current to capture the stress depth profile.

Residual Stress Profiling of Sub-surface Treated Nickel-Based Superalloy using Electromagnetic NDE Method

S. Annamalai, Z. Fan and S. Castagne

Nanyang Technological University

Rolls-Royce@NTU Corporate Lab

School of MAE

Singapore 637460

E-mail: sannamalai@ntu.edu.sg, zfan@ntu.edu.sg, scastagne@ntu.edu.sg

Abstract

To evaluate the whole residual stress profile of sub-surface processes, existing methods such as X-ray diffraction (XRD) or central hole drilling method (CHD) require material removal, which is inherently destructive. A non-destructive residual stress measurement method using eddy current is utilized to capture the stress depth profile. The technique is demonstrated on nickel-based superalloy Inconel 100 (IN100) treated using deep cold rolling and shot peening to show that the method developed for stress profiling can be independent of the sub-surface treatment. This paper presents the experimental results obtained with an experimental set-up based on the commercially available Nortec eddy current instrument and pencil surface probes. Test samples prepared from IN100 by deep cold rolling and shot peening for two different treatment conditions will be presented. The calculated residual stress profile using eddy current (EC) is compared with the equivalent residual stress profile using CHD for penetration depths from (100-550) μm to validate the measurement technique.

Keywords: *Eddy current; sub-surface process; deep cold rolling; shot peening; residual stress*

Introduction

Introducing compressive residual stress on components to improve its fatigue life can be achieved by different sub-surface treatment methods such as shot peening (SP), laser shock peening (LSP), low-plasticity burnishing (LPB) and deep cold rolling (DCR). To reliably assess the remaining life of the sub-surface treated components while in-service, the near-surface residual stress has to be characterized accurately. A nondestructive electromagnetic method using eddy current is utilized to obtain the near-surface residual stress depth profile of sub-surface treated components [1]. Nagy et al. have shown that a nondestructive method based on eddy current conductivity spectroscopy is suited to measure the residual stress of shot peened nickel-based superalloys. The objective of this paper is to study the feasibility of near-surface residual stress depth profiling of two different sub-surface treatment methods such as deep cold rolling and shot peening. The various sub-surface processes typically differ in the amount of cold work put into the material as well as the depths to which compressive residual stresses are introduced. In order to demonstrate the developed low frequency electromagnetic technique for estimating the residual stress profile can be independent of sub-surface treatment, a nickel-based superalloy Inconel 100 (IN100) is selected for this research. Eddy current has great potential because of the stress dependence on electrical conductivity. The standard depth of penetration of eddy current is inversely proportional to square root of frequency. In essence, one can change the penetration depths by changing the eddy current coil frequency. From the conductivity profile, using the known piezoresistivity of the material, the residual stress depth profile can then be calculated. Test coupons were prepared using sub-surface treatment processes such as deep cold rolling and shot peening and treatment conditions varied to induce different levels of residual stress into the material before eddy current spectroscopy was measured.

Equipment Details

The major components of the eddy current system are a portable Nortec 2000D+ eddy current test instrument, multiple Uniwest pencil probes (frequency range 200 KHz – 9 MHz), a multi-function DAQ to digitize analog signals, a PC based LabVIEW data acquisition software and two appropriate conductivity blocks for instrument calibration. A typical eddy current experimental setup is shown in Figure 1.



Figure 1. Typical Eddy Current Experimental Set-up for Low Frequency.

Calibration is an important step in using the test instrument interfaced to pencil probes and certified conductivity standards of known values are required for basic conductivity testing. Conductivity testing is a simple task of setting known conductivity values a priori in the instrument and testing the material once calibration is complete. The basic mode of operation of the eddy current equipment is in conductivity mode where the measured probe coil electrical impedance is transformed to another parameter known as apparent eddy current conductivity (AECC) [2]. Using any two appropriate calibration blocks of known conductivities, four reference complex impedance points are measured with and without lift-off using a non-conducting shim of known thickness (t) between the probe coil and calibration block. Then the experimental measurements of complex coil impedance on the test specimen are evaluated in terms of AECC.

This frequency dependent measured AECC is inverted for the depth-dependent profile of electrical conductivity. Since the conductivity change produced by subsurface treated nickel alloy IN100 is rather weak and it does not vary sharply with depth, the proposed inversion technique is a localized point-by-point absolute AECC measurement over the frequency range. This procedure neglects the exponential decay of the eddy current and integrating effect of this distribution below the surface. Instead it assumes that the measured AECC corresponds directly to the actual electrical conductivity at half the standard depth of penetration. The main advantage of this two-step approach is that the measured AECC is independent of equipment or type of probe coil used for measurement.

Following the inversion procedure, the actual conductivity profile $\sigma(z)$ can be predicted from the measured frequency dependent AECC and is given by

$$\sigma(z) \approx \sigma_a \left(\frac{1}{4\pi z^2 \mu_i \sigma_i} \right) \quad (1)$$

where

- μ_i - Magnetic permeability of the material
- σ_i - Electrical conductivity of the material
- z - Penetration depth of eddy current

The estimated residual stress profile of the sub-surface treated sample is obtained solely using the piezoresistivity relationship of conductivity to stress [1].

$$\frac{\Delta\sigma_i}{\sigma_0} = K_{ip} \frac{\tau_{ip}}{E} \quad (2)$$

Here, $(\Delta\sigma_i = \sigma_i - \sigma_0)$ ($i = 1, 2, 3$) denoted the conductivity change due to the presence of stress, σ_0 is the bulk electrical conductivity, K_{ip} is the electroelastic coefficient and T_{ip} is the elastic stress in the material. The bulk electrical conductivity of the test coupon was measured at the lowest frequency ($f = 200$ KHz), where the standard depth of penetration is approximately 1.35mm, i.e., sufficiently deep to avoid the effects of

sub-surface processes. A dimensionless isotropic electroelastic coefficient ($K_{ip} = 1.58$) for IN100 [8] is utilized. A simple schematic representation of the method to obtain eddy current stress depth profile is shown in Figure 2.

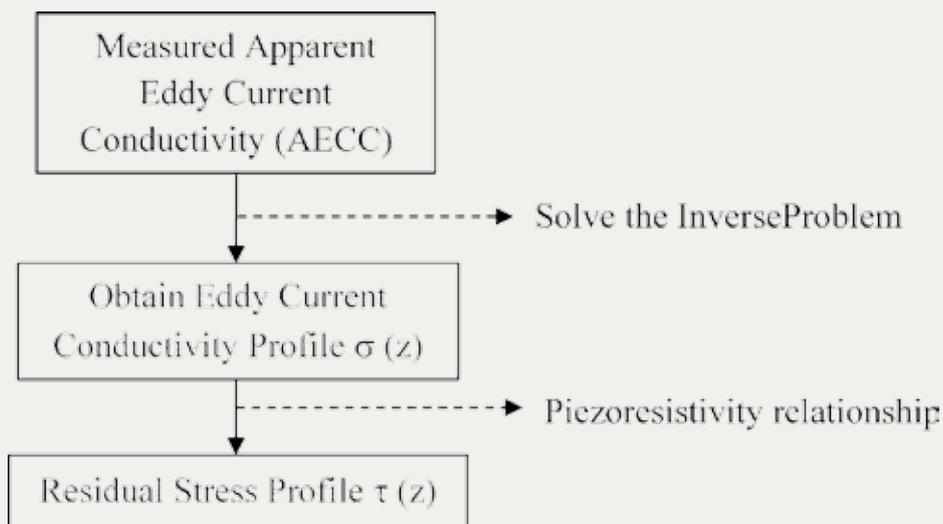


Figure 2. A schematic to obtain Stress Depth Profile using Eddy Current method.

Experimental Results

Results of the experimental investigations for residual stress depth profiling of Nickel alloy IN100 in sub-surface processes deep cold rolling (DCR) and shot peening (SP) are discussed. Sub-surface processes such as DCR and SP can induce compressive residual stresses that are not the same in the lengthwise and crosswise directions after sub-surface treatment. In situations that involve directional stresses acting at a point, it is convenient to define an effective stress that represents a combination of stresses, such as Von Mises equivalent stress. The residual stress profile obtained using the nondestructive eddy current technique is then compared with the Von Mises equivalent residual stress obtained from destructive central hole drilling method (CHD) to validate the accuracy of the nondestructive measurement technique. Each of the residual stress spectra are then normalized to the maximum equivalent residual stress measured by CHD method, for penetration depths of (100-550) μm . The percentage AECC change recorded is with respect to a baseline AECC measured at a frequency equal to 200 KHz. The measured AECC change typically increases as much as 1-2% with increasing induced stress in DCR process as shown in Figure 3. Conditions I and II refers to two different stress depth profiles induced separately into two IN100 test coupons.

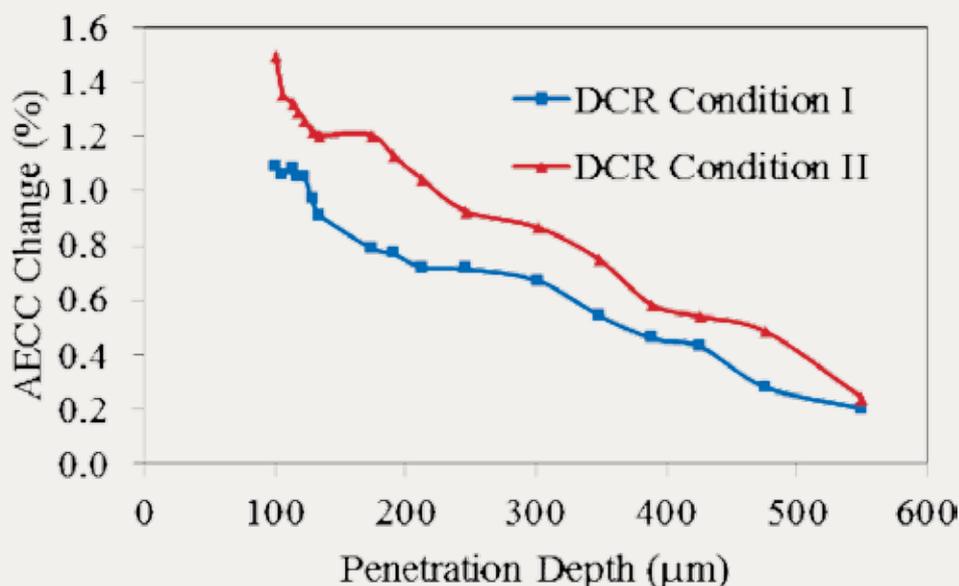


Figure 3. Measured AECC change as a function of depth in IN100 for DCR sub-surface process.

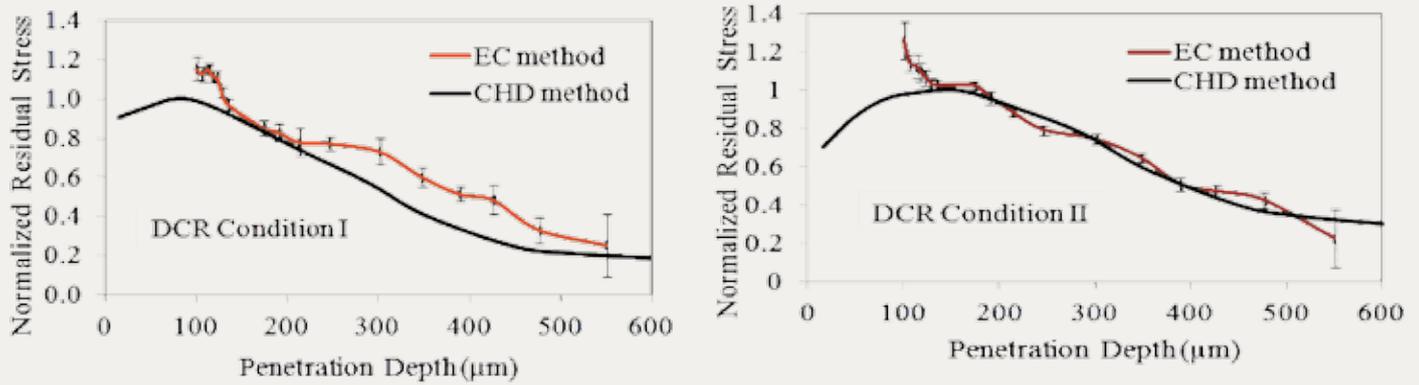


Figure 4. The estimated residual stress profile by nondestructive eddy current (EC) method (plotted with 1-standard deviation) versus the equivalent residual stress profile measured destructively by central hole drilling (CHD) method for condition I(left) and condition II(right) in deep cold rolling (DCR) sub-surface process.

In order to increase the confidence level of these measurements, a number of repeat conductivity measurements were performed. The sample size at each chosen frequency was at least 80 measurements. From the analysis of Figures 3 and 4, one can observe that the AECC change shows very similar dependence on the same depth to that of the residual stress measured by eddy current method. For IN100 residual stress has the same influence on the eddy current conductivity: when residual stress increases, the conductivity also increases. As seen in Figure 4, comparison of estimated residual stress profiles between the nondestructive eddy current method and destructive central hole drilling method reveals there is fairly good agreement between the two methods for penetration depths of (100–550) μm . Results obtained from DCR treated coupons (conditions I and II) indicated that, within the uncertainty of the measurement, the maximum deviation between the two residual stress profiles is within 25%. Eddy current conductivity is a mixed signal that contains information about prevailing residual stress along with a few other influences. The most probable reason for the deviation of curve closer to the surface could be due to plastic strains produced by prior cold work. Studying the influence of the cold work as well as sought near-surface residual stress profile ($<100\mu\text{m}$), requires use of specially designed eddy current probes and measurement systems to extend the inspection frequency range far beyond the 9 MHz. Thus probe design and development is of high interest to obtain good performance for eddy current conductivity spectroscopy of surface treated components.

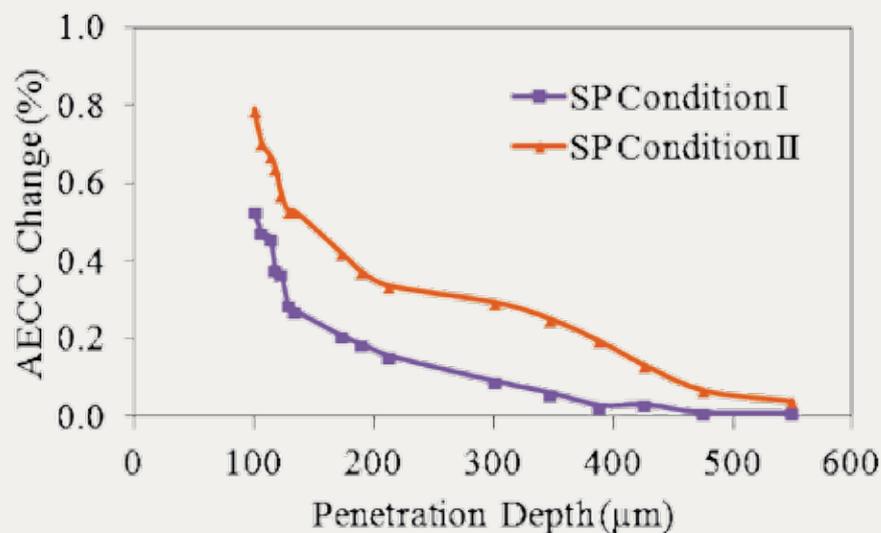


Figure 5. Measured AECC change as a function of depth in IN100 for SP sub-surface process.

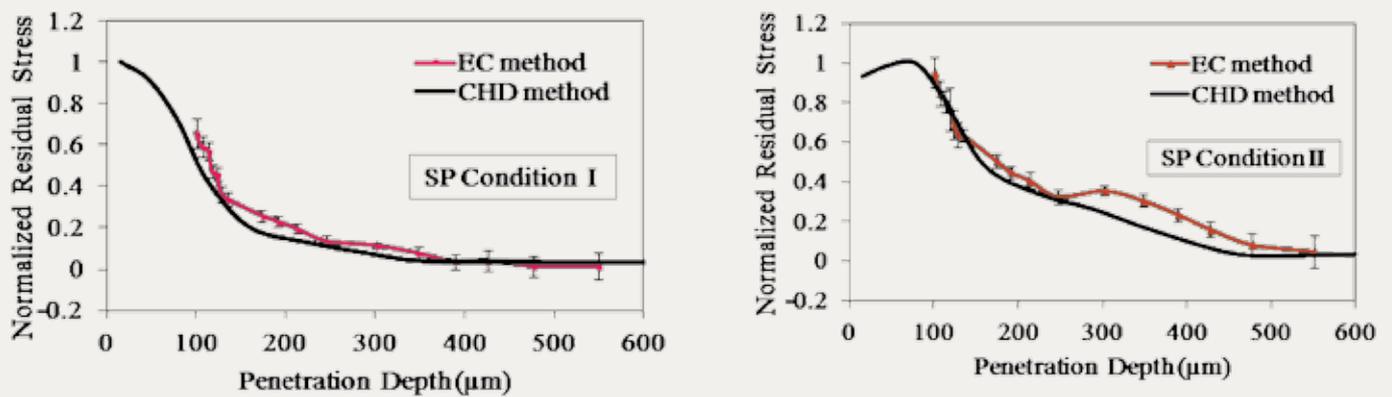


Figure 6. The estimated residual stress profile by nondestructive eddy current (EC) method (plotted with 1-standard deviation) versus the equivalent residual stress profile measured destructively by central hole drilling (CHD) method for condition I(left) and condition II(right) in shot peening (SP) sub-surface process.

Experimental observations indicate that there is a conductivity change due to shot peening process ($< 1\%$ AECC change) as shown in **Figure 5**. This once more confirms that stress influences conductivity and in this case has lead to an increase in electrical conductivity. The residual stress profiles reconstructed from the measured AECC spectra for conditions I and II in shot peening sub-surface process is shown in Figure 6. The general agreement between the nondestructive eddy current residual stress profile and equivalent residual stress profile measured by destructive central hole drilling method is very good for penetration depths of (100-550) μm . These results have indicated that within the uncertainty of measurement, the maximum deviation between the two profiles was less than 20% for both shot peened conditions I and II. It is worth noting that the sensitivity of eddy current conductivity spectroscopy is fairly low as seen in Figure 5, but still sufficient for residual stress profiling in certain surface-treated nickel-based superalloy such as IN100. Similar to DCR process, the plot of estimated residual stress profile of shot peened test coupon is obtained solely using the piezoresistivity relationship of conductivity to stress. The effect of cold work or other factors that may influence the conductivity of the material is not factored into the equation at these depths.

Conclusions

Existing methods for characterization of near-surface residual stress of sub-surface processes are inherently destructive. Currently, feasibility for nondestructive residual stress profiling by eddy current conductivity spectroscopy of nickel-based superalloy IN100 is demonstrated for penetration depths of (100-550) μm . Experimental observations reported in this paper indicate that the technique adopted for stress profiling of nickel-alloy IN100 treated using deep cold rolling (DCR) or shot peening (SP) is independent of sub-surface treatment. In order to reconstruct the critical near-surface part of the residual stress profile in sub-surface processes requires inspection frequencies to be far beyond the 9 MHz. The influence of cold work on the eddy current conductivity is also one of the contributing factors for overestimation of stress near to the surface (100 μm). Therefore a deeper understanding of its influence and its correlation to stress will be the task for future work.

Acknowledgements

This work was conducted within the Rolls-Royce@NTU Corporate Lab with support from the National Research Foundation (NRF) Singapore under the Corp Lab@University Scheme.

References

- [1] B. A. Abu-Nabah, F. Yu, W. T. Hassan, M. P. Blodgett and P. B. Nagy, *Nondestructive Testing and Evaluation* 24, 209-232 (2009).
- [2] F. Yu, M. P. Blodgett and P. B. Nagy, *J. Nondest. Eval.*25, 17-28 (2006).
- [3] Y. Shen, C. Lee, C.C.H. Lo, N. Nakagawa, and A.M. Frishman, *J. Appl. Phys.* 101(2007), p. 014907.



Glossary for Radiation safety:

- **Acceptable Limits:** Limits acceptable to the regulatory body for accident condition or potential exposure
- **ALARA :** As Low As Reasonably Achievable
- **AERB :** Atomic Energy Regulatory Board
- **Certification (of Personnel):** The formal process of certifying personnel by an authority for performing the various activities in nuclear and radiation facilities.
- **Collective Dose:** An expression for the total radiation dose incurred by a population and defined as the product of the number of individuals exposed to a source and their average radiation dose.
- **Design Limits:** Limits on the design parameters within which the design of the structures, systems and components of a nuclear facility have been shown to be safe.
- **Deterministic Effects:** A radiation effect for which generally a threshold level of dose exists, above which the severity of the effect is greater for a higher dose
- **Dose:** A measure of the radiation received or absorbed by a target.
- **Dosimeter:** A device, instrument or system, which can be used to measure or evaluate any quantity related to the determination of either absorbed dose or equivalent dose
- **Exposure:** The act or condition of being subject to irradiation
- **Licence:** A type of regulatory consent, granted by the regulatory body for all sources, practices and uses for nuclear facilities involving the nuclear fuel cycle and also certain categories of radiation facilities.
- **Radiation Weighting Factor:** Multipliers of absorbed dose used for radiation protection purposes to account for the relative effectiveness of different types of radiation in inducing health effects.
- **Radiation Worker:** Any person who is occupationally exposed to radiation and who in the opinion of the regulatory body should be subjected to radiation surveillance.
- **Radiological Safety Officer (or Radiation Safety Officer):** Any person who is so designated by the employer and who, in the opinion of the competent authority, is qualified to discharge the functions outlined in the Radiation Protection Rules, 1971
- **Regulatory Inspection:** An examination through review of documents, observation, measurement or test undertaken by or on behalf of the regulatory body during any stage of the regulatory consenting process, to ensure conformance of materials, components, process etc.
- **Safety Limits:** Limits upon process variables within which the operation of the facility has been shown to be safe.
- **Stochastic Effects (Radiation):** Radiation effects generally occurring without a threshold level of dose whose probability is proportional to the dose and whose severity is independent of the dose



Mirror Image

It is very interesting to be back and to mirror views and reviews, technical and non-technical through this newsletter. Field of Non-Destructive Testing is all about images that tell the inside story of materials and structures. Physics holds the mirror, technicians and engineers look through the glasses to find a myriad of meanings to the images they see. Some find the shadows while others gauge the reflections and yet others interpret reverberations.

We had a great event NDE 2016 and to gauge it as a success is underplaying the magnitude of appreciation and accolades it won from the NDE community of the nation. There is a euphoria of excellence in the way the society is run, a legacy, carefully guided and built by host of NDT professionals for over three and half decades. No doubt mirror images of future would be magnified.

What are the new thoughts in Non-destructive Evaluation a young friend asked? This set my thoughts rolling. Birds and NDT have something in common. A feather of a bird can give the air pollutants when chemically evaluated. Organic pollutants can be measured in a single tail feather of predatory birds and that concentrations in feathers reflect to a certain extent concentrations in internal tissues. Birds have thus been identified as biomonitors and can contribute in the study of climate change.

Migratory birds may use two electromagnetic tools to find their destinations: one that is entirely innate and another that relies on experience. A young bird on its first migration flies in the correct direction according to the Earth's magnetic field, but does not know how far the journey will be. This is very much similar to a fresher in NDT who is guided by the principles to carry out the test but falls short of interpreting the result. At this stage the bird is in the position of a Boy Scout with a compass but no map, until it grows accustomed to the journey and can put its other capabilities to use. With experience it learns various landmarks and this "mapping" is done by magnetites in the trigeminal system, which tell the bird how strong the field is. Because birds migrate between northern and southern regions, the magnetic field strengths at different latitudes let it interpret more accurately and let it know when it has reached its destination. There is a neural connection between the eye and "Cluster N", the part of the forebrain that is active during migrational orientation, suggesting that birds may actually be able to see the magnetic field of the earth. Does it not sound familiar to NDTians? Science mirrors the image of nature.

KR Mohan Ananthanarayanan

Editor

Image

Published on behalf of Executive Committee, **ISNT Thiruvananthapuram Chapter**.

Editorial Board: Shri K R Mohan Ananthanarayanan, Shri Girish N Namboodiri, Shri Sambamurthy E, Shri Binu B, Shri Roykuttan K K, Shri Murugesan, Shri S Harikrishna, Shri Rajesh L.

Address for communication: NDTF/RPP/PRSO Entity, VSSC, ISRO Post, Thiruvananthapuram

E-mail: girish_nn@vssc.gov.in