A Diagnostic 'tool' to prevent the consequences of material failure

I Sikakana
Department of Physics and Non-Destructive Testing, Vaal University of Technology, Private Bag x021, Vanderbijlpark, 1900, South Africa

E-mail: ike@vut.ac.za

Abstract. In materials' manufacturing, evaluation and /or characterization is a key final stage in the production process. This quality assurance tests whether the product meets an industry norm or specified standard required by the customer. The evaluation is also required on machinery / plants parts that are already in operation. The parts are periodically 'tested' to ascertain as to whether they can still function safely and as originally designed. The evaluation, characterization, testing is conducted using techniques that do not damage these parts / materials. This novel way of materials' examination; referred to as Non-Destructive Testing / Evaluation (NDT/E); is finding increasing applications in numerous industries. This paper focuses, first, on the use of NDT/E in selected industries and its critical nature in the safe operation of plant machinery and structures. Secondly, an overview of the education and training required in NDT/E is discussed. The qualification offered at the Vaal University of Technology (VUT) and its impact on the NDT/E profession in South Africa is reflected upon. Thirdly, the rewards of an NDT/E career are discussed. This is contrasted with the perceived low profile of NDT/E amongst practicing engineers in South Africa. Lastly, an argument for the urgent need of a legislative framework for the regulation and recognition of NDT/E qualifications and certification in South Africa is advanced. It is emphasized that this is a necessary measure to have accountability and a code of ethics entrenched in this growing profession.

1. Introduction

Non- destructive materials evaluation uses a variety of techniques to distinguish between indications that are to be expected – normal – and those that are not to be expected – abnormal. Sufficient technique training and experience on material properties' behaviour is essential.

These abnormal indications may be due to in-service degradation through stress corrosion cracking, steady and /or cyclic loading conditions which may lead to the materials' catastrophic failure. NDT/E thus is a mandatory inspection requirement for the safe operation of plant machinery.

Abnormal indications are then assessed for their severity in terms of the continued use of the material. The diagnostic process involves:

° Correct identification of indications on the material.
° Assessing the severity of the indications, i.e. materials' 'fit-for-the purpose'.

If the material is not 'fit-for-the purpose' it was manufactured / designed for, then recommendations can either be to repair or retire / replace it.

If the material is still 'fit-for-the purpose', a residual life assessment must be done to include the operational risk profile, hence future inspection schedules.

The inspection techniques can range from very rudimentary to more sophisticated and highly technical in nature.

1.1. Sight

Sight remains one of the most powerful and indispensable diagnostic tool used by an NDT technician. It is therefore obvious that lighting conditions are a key and pivotal requirement for a successful inspection process. While lighting conditions may be a constraint, there are other limiting factors, like optical instrument resolution and accessibility of the area to be inspected; complex geometry of the material.

1.2. Hearing

Listening to sound wave propagation in a material is another basic NDT technique. The resonance effects are the characteristics that distinguish the different frequencies generated. Any change in the frequencies is an indication of the differences in the material structure near the impact location. Sound wave propagation also has its limitations, like technician experience, knowledge of the technique and the fact that the human being has an audible range of frequencies that is between 20 Hz and 20 kHz.

These limitations have resulted in the development of other techniques to complement and improve the detection of indications.

2. Typical Industry Utilization and Techniques for Inspection

Inspection procedures are applicable in all industries and equipment to be tested. These procedures are established and written according to code specification applicable.

2.1. NDT/E is applied in a wide spectrum of industries as shown in table 1 below

Table 1. Type of industry and structures, where utilized and causes of indication.

Industry	**Aerospace**	**Petrochemical / refineries**	**Power Generation**	**Rail**	**Transportation Road**	**Marine**
Typical Structures	Engine compressors Airframe	Pipelines Pressure vessels	Boilers Turbine blades	Carriage frames Tracks Wheels	Wheel hubs Paving Bridges	Ship hull Engine rotors Cranes
Where	Body rivets Joints	Welding tanks	Welding Joints	Joints on Castings	Hinges General state	Welding Joints
Major Causes	Take-off landing	Fatigue Humidity	Cyclic loading	Loading	Loading	Loading

Other industries include the metal manufacturing, particularly steel, sugar and paper mills and on- / off-shore oil platforms and associated infrastructure.

The Photos shown in figures 1 and 2, below are the consequences of material failure [1].

Winchester Kentucky US – January 27, 2000 (Crude Oil Pipeline, Fatigue, USD 7,100,000)

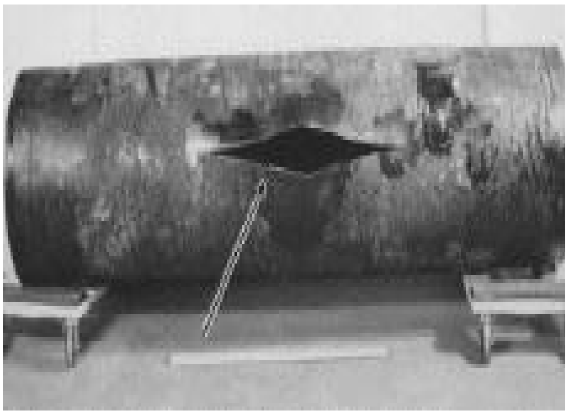


Figure 1. Winchester fatigue cracked pipeline

Longford Victoria Australia -September 25, 1998 (Brittle Fracture, Gas Processing Plant, 2 killed, 8 injured, USD 160,000,000/171,000,000)

Figure 2. GP 905 Heat Exchanger of Longford Gas Plant

2.2. Categories of NDT/E Techniques, shown in figure 3 [2]

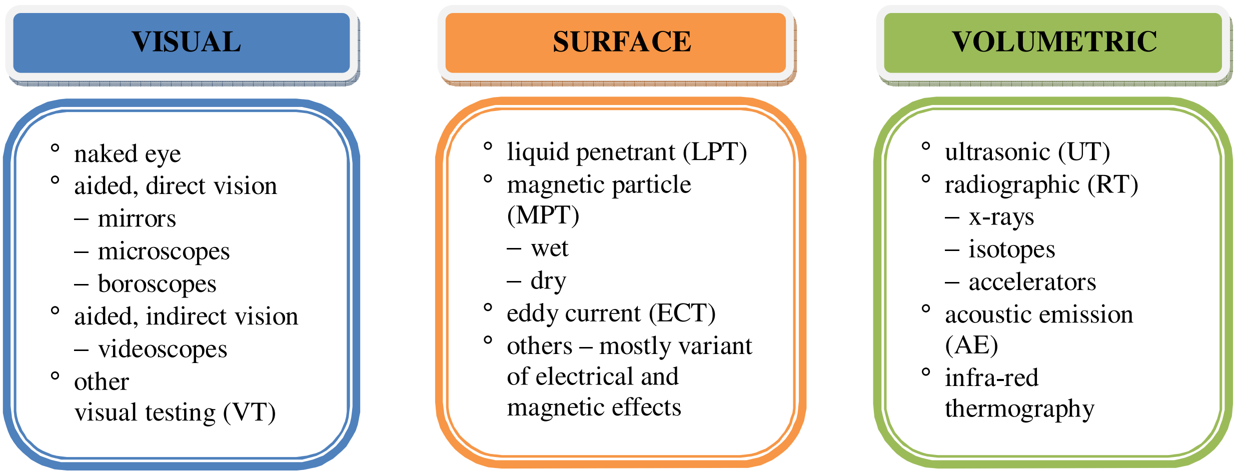


Figure 3. Main categories of the basic NDT/E techniques.

2.3. Type of flaws / defects that may be present in a welded metal

The figure 4, below shows the different types of indications that may be present in a welded plate [3]. The labels suggest the basic NDT techniques that can be used to detect the different types of indications.

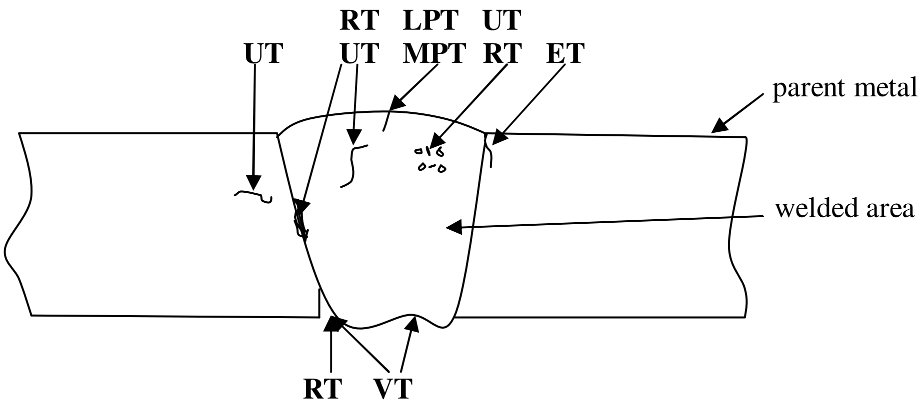


Figure 4. Application of NDT techniques on a butt weld.

3. Education and Training

The education and training scenario in South Africa has been mainly through the use of the ISO 9712 and SNT-TC-1A. The former having private schools issuing certificates that are nationally (or internationally) recognized by the big consumers of NDT and the latter applicable to plants / equipment conforming to American standards.

3.1. Certification

The South African Qualification & Certification Council (SAQCC) – non-destructive testing division uses ISO9712 for local training.

The British Institute of Non-Destructive Testing (BINDT) affiliated Personnel Certification in Non-destructive testing (PCN) also uses ISO9712 together with EN473 and is applicable locally and most of Western Europe.

SNT-TC-1A is the original American Society for Non-destructive Testing (ASNT) training standard and applicable in North America and around the world where American plant / equipment is operated.

NDT certification does not confer professional status, but only a temporary license of five years to apply a particular technique in a specified industry [4].

3.2. Qualification

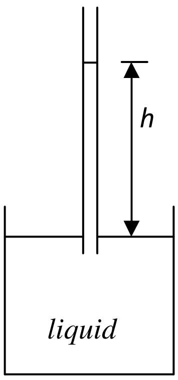
The Vaal University of Technology offers a ***National Diploma: Non-Destructive Testing***. This is a full qualification recognized the Department of Higher Education and Training (DoHET). The main purpose for this qualification is to offer a professional development path for NDT practitioners and also to be a link for the effective utilization and optimization of NDT techniques in the Southern African region – which has its own challenges, different from other parts of the world.

VUT further strives to offer NDT education that seeks to produce NDT specialist who understand the inspection systems and through the collection of data, competent analysis can be performed using well understood theoretical principles.

The focus at undergraduate level is:

- Basic NDT techniques, Visual Testing, Liquid-dye Penetrant Testing, Magnetic Particle Testing, Eddy Current Testing, Radiographic Testing and Ultrasonic Testing. For each of these techniques, an in depth treatment of the physics & chemistry principles behind these techniques constitutes the theory module. The practical module requires laboratory training with scrap specimen and standard specimen.

  As an example, in the theory of LPT, the study of the capillary effect includes knowledge as depicted in figure 5.



The understanding of the derivation of the liquid column height, *h* relationship is expected:

$$h = \frac{2\,\sigma\,\cos\theta}{\rho\,g\,r}$$

Where σ is the surface tension, θ the contact angle, ρ the liquid density and g the gravitational acceleration.

Figure 5. A thin cylindrical tube, radius ***r***, in a liquid bath with the liquid column height being ***h***.

- Establishment of research work that impact on the curriculum, particularly in advanced applications of UT, ET and RT.
- Collaboration and partnerships with industry to solve challenges that are encountered in the field.

The programme is a three year qualification as follows:

Year 1:

- Introduction to Non-Destructive Testing, including VT
- Basic Sciences – Introductory tertiary Chemistry, Mathematics and Physics
- English language Communication Skills
- Engineering Drawing and Metallurgy
- Two Surface Techniques – LPT & MPT

Year 2:

- Radiographic Testing
- Eddy Current Testing
- Ultrasonic Testing
- Welding and Foundry Technology
- Quality Control & Assurance
- Fracture Mechanics

Year 3:

- Work-Integrated Learning at a partner company

  At this stage, Level certification may be included.

Future registration of graduates with the Engineering Council of South Africa (ECSA) is envisaged.

Below, in table 2, is a comparison of the vocational and academic streams for aspiring NDT professionals [5]. The professional engineering registration column is included as a perspective for future desired recognition of the qualifications.

Table 2. Envisaged future NDT professional development qualification matrix

VOCATIONAL	ACADEMIC	PROFESSIONAL ENGINEERING REGISTRATION
	Doctoral Degree	
	Masters Degree	
	Bachelor Degree (4-year)	Engineer
	Postgraduate Diploma	Technologist
Level 3	National Diploma (3-year)	Technician
Level 2 **Level 1**		Certificated Engineer
NATIONAL SCHOOL CERTIFICATE OR OTHER ENTRY LEVEL		

4. Regulatory Framework

There is yet no holistic legislation that regulates inspection of critical plant machinery / equipment. The Occupational Health and Safety Act concerns itself with working conditions, and indirectly states that equipment used in the workplace must be safe to operate. Most plant / equipment maintenance is guided by 'original equipment manufacturer' (OEM) schedule for their safe operation in conjunction with relevant code specification applicable. Presently, inspection legislation targets only critical equipment, like the new 'pressure equipment regulation' (PER) which came into effect in October 2009, with certain aspects only effective in April 2011.

Where there is no stated overt inspection requirement or regulatory monitoring mechanism, self general monitoring, which is non-code, and minimally only assesses the present condition of the plant or equipment. These situations are a mine field when accidents occur; since to establish what went wrong, why and who is to take responsibility is almost impossible. Litigation by the State or individuals rests on the recommendations of the investigation of the accident, which always take years and most of the times not conclusive.

5. A Rewarding Career

As stated in table 1, NDT is applicable in a wide range of industries. This wide applicability opens job opportunities anywhere in the world. South Africa presently has a skills shortage in NDT personnel. This is all the more starkly evident during maintenance 'shut downs' of the power stations and petrochemicals facilities, when foreign workers are employed. Although – at times – during these plant 'shut downs', there are long working hours, the remuneration for qualified technicians with the appropriate experience is good.

Most of all, an NDT technician will always feel satisfied when planes fly to their destinations without incidence, power stations generate electricity without unscheduled shut downs and the refineries produce their varied liquid products without an accident. In short, the NDT technician has contributed to their safe operation and possible loss of human life.

6. Conclusion

NDT/E as a diagnostic tool for material condition is effective when taking into consideration the operational history of material / equipment. Apart from being a diagnostic tool, it can further contribute to future design of the equipment and manufacturing processes.

NDT/E is continually challenged to devised new, novel and technologically innovative ways to inspect more advanced materials. In the past decade the inspection of composite materials, now used in the manufacture aircraft body and wings, has made great strides.

There has yet to be a structured career development for NDT personnel, hence the VUT qualification programme promises to radically change this state of affairs. It is further noted that in most formal undergraduate engineering qualifications, NDT is not included as part of their curriculum. As a critical aspect of materials evaluation, engineers need to be conscientious and be taught about its importance.

With a stricter regulatory regime, there will be more accountability and adherence to a good code of ethics, something that has been missing all along.

Acknowledgements

I wish to acknowledge Ms MM Cock for her vision, Prof BR Mabuza for his passion for NDT and the NDT staff – past and present – for their perseverance and dedication. This paper has been inspired by all my past NDT students.

References

[1] Abduh M 2008 The 50 Major Engineering Failures (1997 – 2007) (abduh137.wordpress.com)
[2] Aestroem T 2008 From fifteen to two hundred NDT methods in fifty years (Shanghai, China, 25 – 28 October) (17^{th} WCNDT)
[3] Rihar G 1999 Selection of an NDT method and the extent of testing (NDT.net vol 4 no 5)
[4] ISO 9712:2005(E) Non-destructive testing – Qualification and certification of personnel (10.3 Validity) p 16
[5] Gallagher M 2010 An integrated education programme for NDT professionals (ICNDT Journal vol 8 no 4) ed D J Marshall (Northampton: ICNDT) pp 3-4