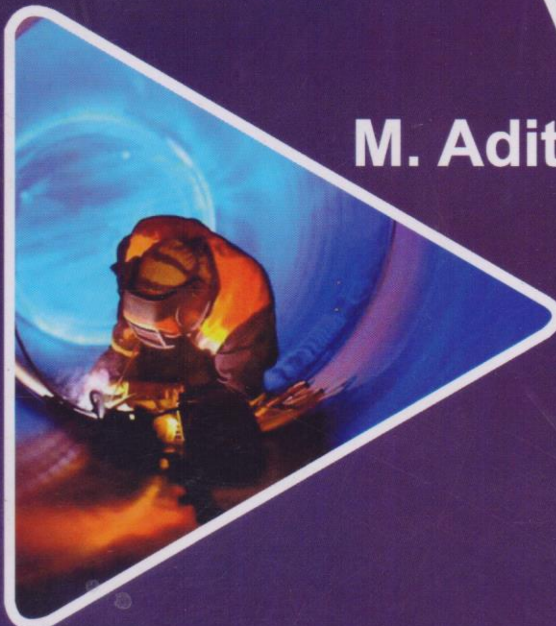
Non-Destructive Testing



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by

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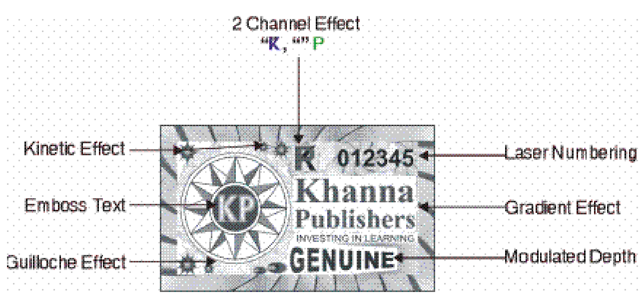

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Preface

Frequently there is an urgent need to test a material or a part to know whether or not it meets design specifications or contains cracks, hard spots or any other flaw that may seriously affect the design and performance requirements.

In this respect *Non-Destructive Testing plays an important role,* since it enables testing of a part without destroying it and still conclude whether the part is defective or not and whether there is a reasonable assurance that the part or product will be safe, when used in its intended application.

While measurements and inspection by gauges and various measuring instruments provide a quantitative information about the dimensions and tolerances, a qualitative information concerning the various flaws or defects is reading and easily made available by NDT at a reduced cost in the shop floor itself, so that corrective action can be taken immediately, so as to increase the reliability and quality of the product.

Having realized the importance of NDT in the manufacturing and production, many universities in India have introduced a full-fledged course on NDT in Mechanical Engineering Curriculum.

—Author

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1

Visual Methods of NDT and Metallography

In *Destructive Testing*, the test sample or sometimes actual component gets destroyed during the process of testing and analysis. Examples of this type of testing include tensile testing, compression testing, torsion testing, impact testing, etc.

In *Non-destructive Testing*, the specimen do not get destroyed during the testing and analysis. NDT do not alter the products chemical or physical properties. Examples are magnetic particle testing, radiography (X-ray) testing, ultrasonic flow detection, etc.

Different types of destructive tests and non-destructive tests are shown in a tabular form.

Table 1.1. Mechanical Testing (Different methods available)

Destructive Testing of metals, alloys and materials	*Non-destructive testing (NDT) or Non-destructive evaluation of metals and alloys*
1. Tensile testing	1. Radiography (X-ray testing)
2. Compression testing	2. Ultrasonic testing
3. Hardness testing	3. Magnetic testing
4. Shear testing	4. Magnetic particle inspection
5. Impact testing (Izod impact testing)/Charpy impact testing.	5. Liquid penetrant testing
6. Torsion testing	6. Acoustic-emission technique
7. Fatigue testing	7. Eddy current testing (ECT)
8. Creep testing	8. Ellipsometry/Interferometry
(Loading and type of stress introduced in different types of destructive testing methods shown in Fig. 1.1.	9. Thermographic inspection
	10. Remote field testing
	11. Magnetic flux leakage testing

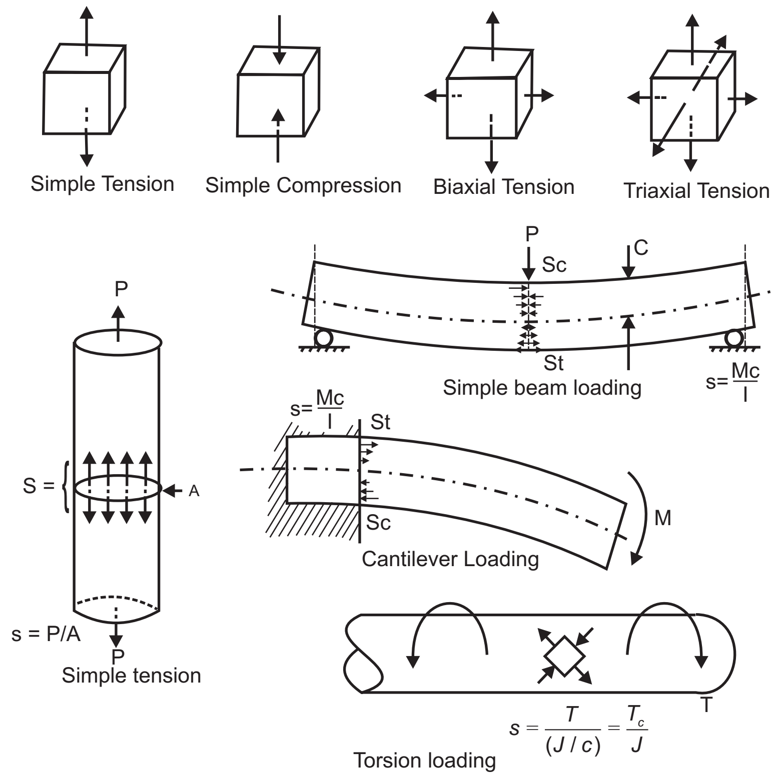


Fig. 1.1. Loading and type of stress caused in various destructive testing methods.

M : Bending moment
s_t : Maximum stress in tension
s_c : Maximum stress in compression
c : Radius of circular section
S : Tensile stress, compressive stress or shear stress
T : Twisting moment (or) Torque
I : Moment of inertia of the section
J : Polar moment of inertia of the section

Q.1. What is the importance of NDE (Non-destructive evaluation)?

Ans. Reliable non-destruction evaluation/testing will enable the product or *part* designer to identify the areas (features) which needs to be *critically examined and redesigned*. It will also help the manufacturing engineers to improve their processes so that the *integrity of the part* under load/service conditions do not get compromised. NDT methods can be used to detect defects in materials and products and to determine the properties or materials.

Non-destructive inspection (NDI). Helps in the prediction of *remaining life of the component* with due consideration of the nature and extent of flow(s).

Non-destructive testing methods are *less expensive*.

NDT also helps in assessing the *reliability of the part*.

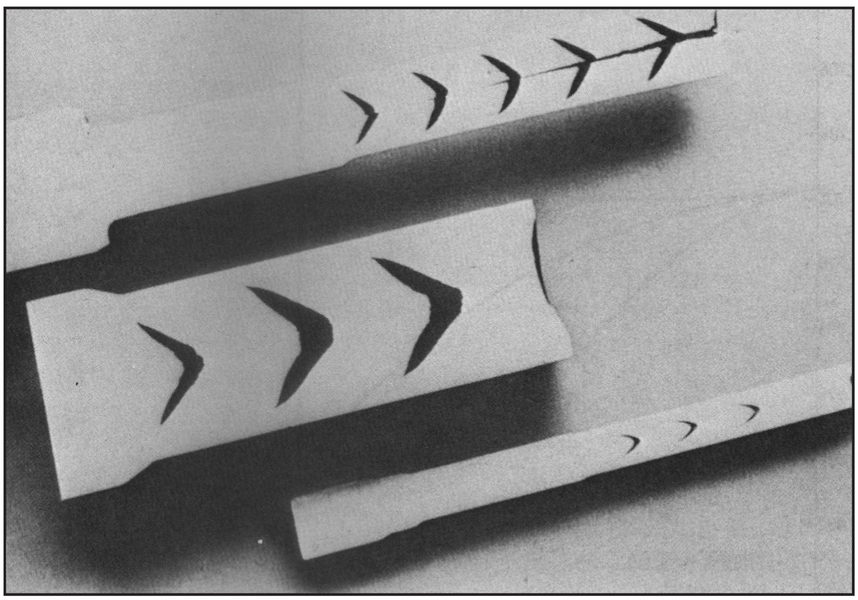
Q.2. Limitation of NDT, if there is any?

Ans. NDT methods *do not provide quantitative information on the flows:*

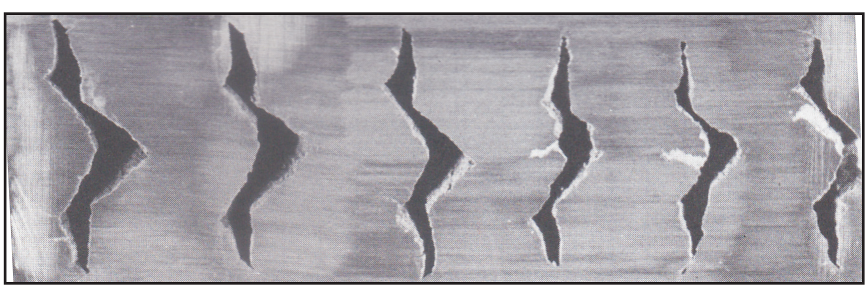
Some of the methods are costly (*e.g.*, X-ray radiation equipments).

Q.3. How is visual inspection carried out?

Ans. This is the cheapest and easiest method of NDT. Defects such as flows, cracks, marks and scratches/grooves and scouring marks can be observed by *naked eye*. Sometimes magnifying glasses are used; microscopes are also used in visual examination. Cracks formed as in Fig. 1.2 can be easily identified.



(*a*)



(*b*)

Fig. 1.2. (*a*) Centreline cracks in extruded steel rod,
(*b*) Cracks formed in cold rolled Molybdenum bar.

Visual-optical methods can detect *surface cracks*, porosity easily. Visual tests are inexpensive, simple, easy and fast. Some of the cracks are observed as light and dark lines. Surface under inspection must be clean and well illuminated.

In more of the cases, *crack is initiated at the surfaces*, when the stresses caused by the service load exceeds the maximum allowable stress of the material. (Fig. 1.3).

Most failures, cracks originate from the surface : due to Bending, Torsion and Fatigue, Stresses

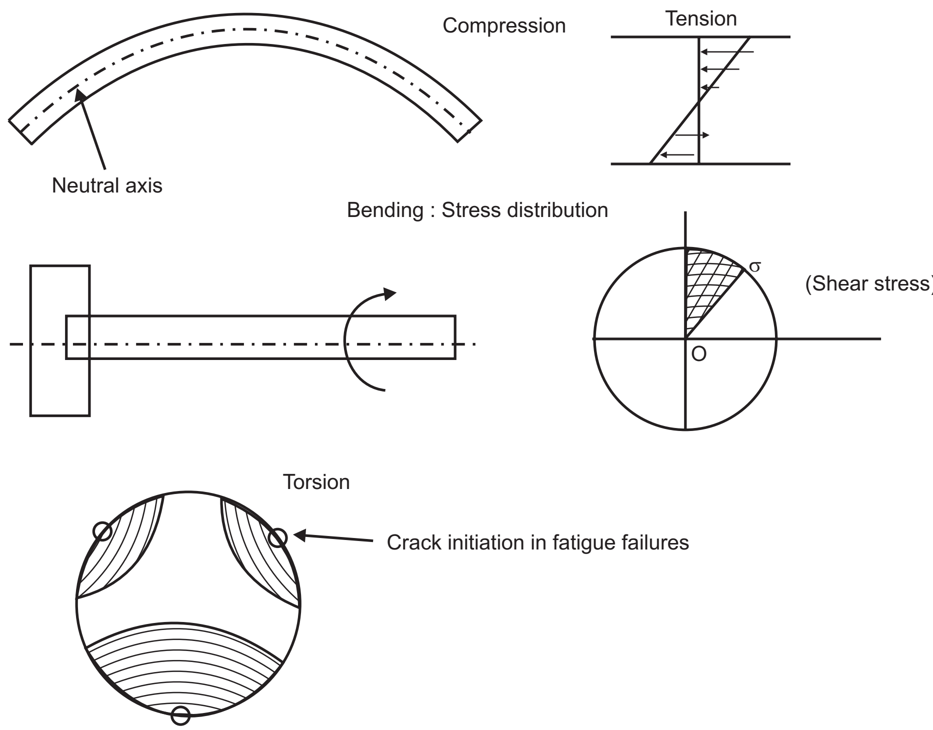


Fig. 1.3. Formation of surface cracks.

Most of the *welding defects* such as cracks, shrinkage, undercut and lack of penetration can be easily detected by the welder himself visually.

Metallography reveals the structure (and micro structure) of metals and leads to better understanding of the relationship between the structure and properties of steel and other metals.

With the aid of modern developments such as Electron Microscope and the Scanning Electron Microscope, it is now possible to obtain a much deeper insight into the structure of steel than was possible only many years ago.

—Bofors Handbook, 1967, UK

NDT helps in Remnant life (residual life) assessment of equipment critical parts and their condition so that preventive actions can be taken before the actual breakdown of the component. NDT helps in *conditioning monitering of the equipment* during their working itself.

Q.4. What is meant by In-situ Metallography?

Ans. In-situ metallography means that the metallurgical structures/microstructures of steels and alloys *can be observed in the shop floor / heat treatment plant itself* instead of taking the specimen/heat treated metal to the metallurgical laboratory for testing and analysis.

The heat treatment process parameters such as temperature, rate of heating and Quenching and time periods can be adjusted and monitored during the process itself so that best results of heat treatment can be obtained. In-situ metallography saves considerable amount of time, control of the process and quick evaluation of micro-structures are possible, and better quality control.

In-situ *metallographic appraisal* method can check

– depth of hardened layers (*e.g.* as in *case-hardening*)
– grain size
– non-metallic impurities
– sub-microscopic pin holes
– different phases in cast structure/during the heat treatment stage.

In-situ metallographic methods use polishing, etching in a suitable acidic solution and viewing under a *metallurgical microscope* with high magnifications (*e.g.* M100).

Picture of a metallurgical microscope is shown in Fig. 1.4. Microstructures can be magnified (in some cases up to 250–500) and can be studied under an illuminated light of the microscope.

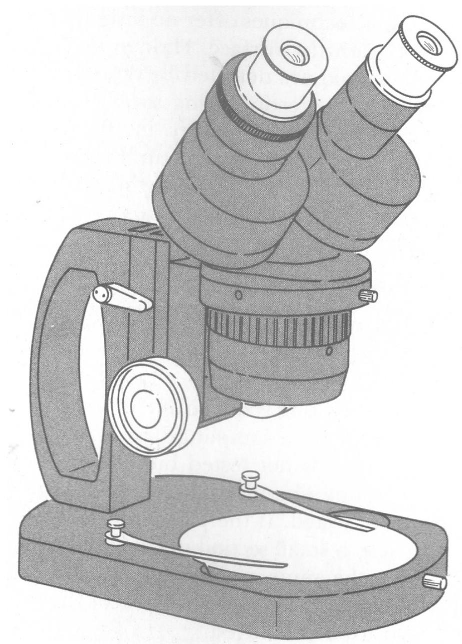


Fig. 1.4. Picture of metallurgical microscope to study metallurgical and microstructures of metals; different magnification are available (M × 100); polishing and etching of specimen done before viewing under microscope.

Some of the metallurgical microscopes are equipped with photographic attachment and can be used for permanent record of the image for future studies and failure investigations. Details of metallurgical microscope are given in the *Appendix/Glossary* at the end.

Metallurgical microscopes can also be used for study and measurement of micro-hardness variations in the surfaces of specimen using a micro-indentor attached to a microscope. A magnified view of a micro-indentor is shown in Fig. 1.5.

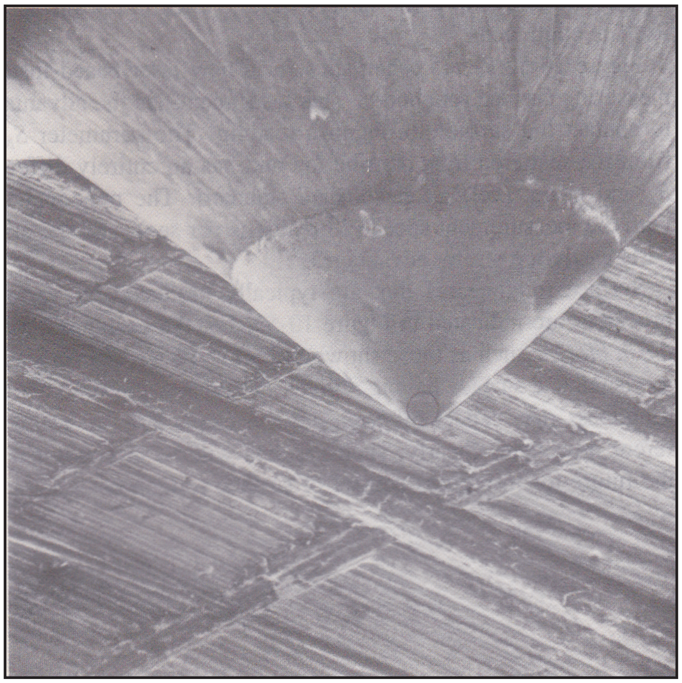
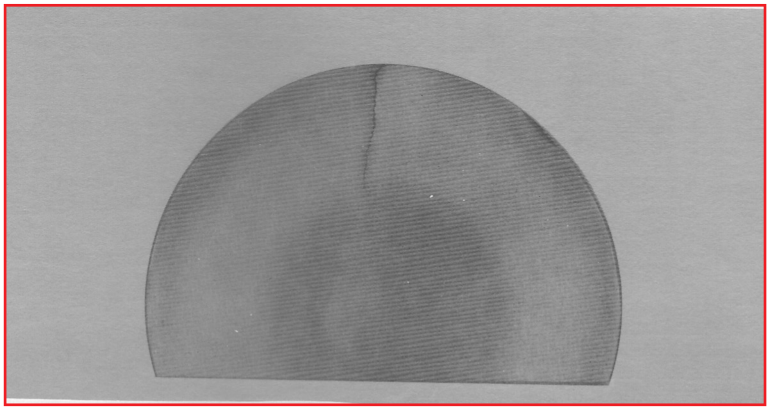


Fig. 1.5. For micro-indentations (to measure micro-hardness of surfaces under a metallurgical microscope) micro-indentors made of diamond of tip dia : 0.01 mm are commonly used.

NDT is carried out in such a way that original product's integrity and surface texture remains unchanged (*i.e.* material or its surface is not destroyed or altered as a result of testing).

Metallography involves the studying of metallurgical/micro structures of metals and alloys.

(*a*) *Polishing and Etching* is a technique used in studying the metallographic structure of alloys. The surface to be studied is polished finely and the surface is subjected to the action of an acid solution. The common etchant used is 50% HCl and 50% water solution, and kept for drying for about 15 to 45 minutes. The etched surface is viewed under a metallurgical microscope and defects such as surface cracks, internal shrinkage cracks, and segregations and inclusions and dendritic patterns can be observed (Fig. 1.6). Higher magnifications of the localized surfaces will give better views (*e.g. X* 215).



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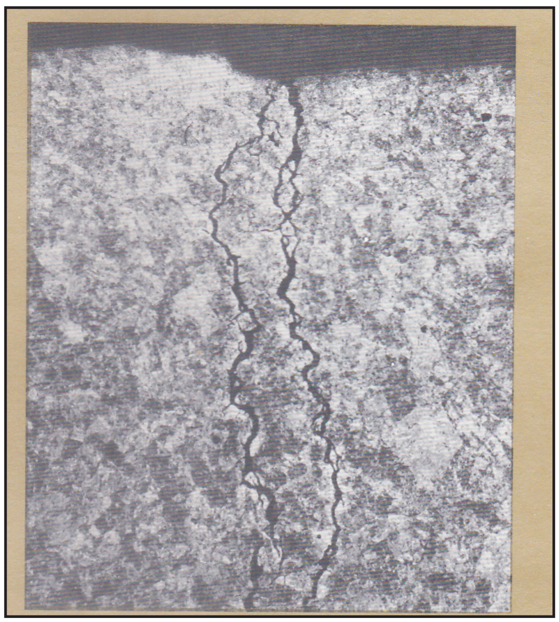


(*b*)

Fig. 1.6. (*a*) *Surface crack* appearing on the round outer area of the component. (X1) nital etch; material: quenched steel. (*b*) The *same crack propagating vertically down into the interior of the* material (X 100); Nital etch; material : quenched steel.

Different etchants are available depending on the allow to be observed. The specimen can be heated slightly to obtain even drying. For polishing, diamond pastes are also available in different grades/mesh number.

This technique can be adopted in laboratories, shop floors and heat treatment plants for quick evaluation of surfaces. Sometimes chrome acid etching is also used.

Properties of a metal can be interred from the examination of the polished and etched surface.

(*b*) *Macroscopic deep etch test*: This method is used to detect discontinuities in the structure of steel after heat treatment or welding. The method can also be used to determine the depth of the hardened layer (*e.g.* after case hardening). The section/surface must be polished with every cloth and etched. Sometimes, the etching time may vary from a few minutes to 30 minutes. Different etchants (of reagents or aqueous solution of a mixture of nitric acid, hydrochloric acid or sulphuric acid) are available depending on the purpose/type of defect to be identified and the micro-structure to be studied.

Q.5. List the types of defects (or sometimes called "flaws") that can be identified by NDT methods.

1. Cracks occurring during metallurgical processes like heat treatment or during service.

   (*a*) Inter-granular (or inter-crystalline) cracks, along the grain boundaries (Fig. 1.7).

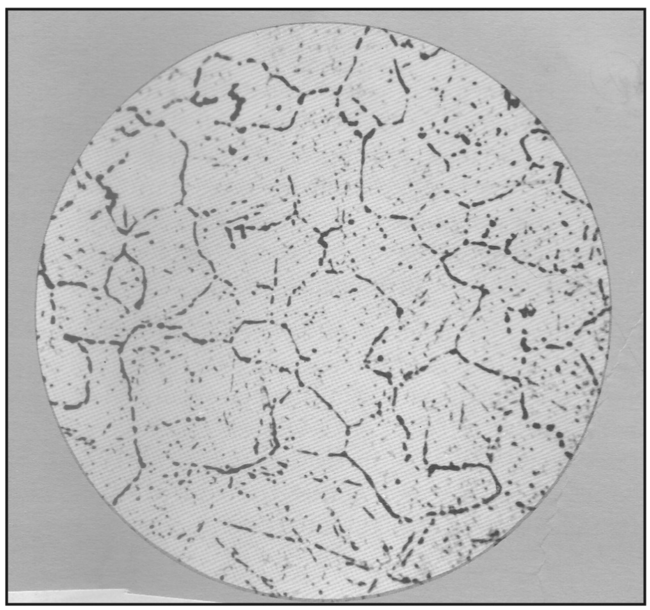


Fig. 1.7. Grain boundary cracks appearing along the carbide grains (magnification: X 500)

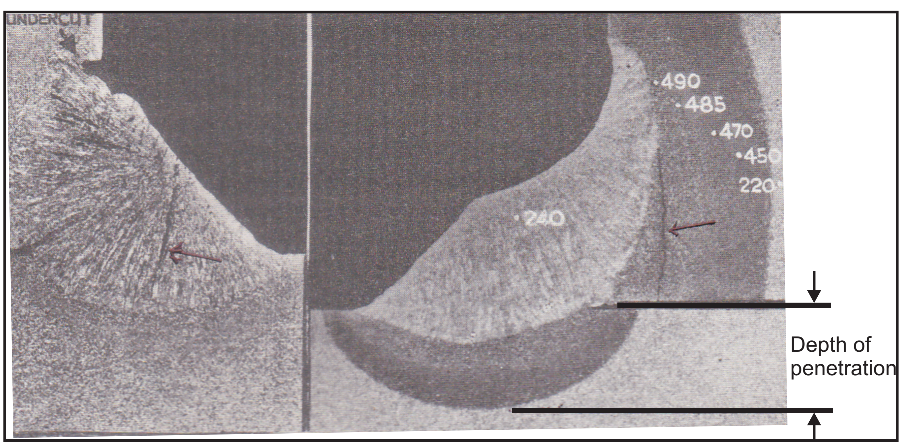
   (*b*) Trans-crystalline cracks across the grains of the metals.

2. Grinding cracks, due to excessive localized heating during grinding operations (sometimes refers to as burnt-out layers).
3. Flakes are internal fissures usually occurring in forged parts, can be detached by ultrasonic testing.
4. Voids and porosity, and entrapped gases and blow holes.
5. Non-metallic inclusions.
6. Internal bursts as in forged parts.
7. Hydrogen Embrittlement. Hydrogen enters during steel making process itself or by subsequent heat treatment process or during welding. This can be observed in fractured surfaces.

8. Brittle Fracture or *Brittle Failure*, resulting in formation of cracks (Fig. 1.8); occurs in hardened carburized case (surface); due to stress concentration. When there is a sharp change in cross-section of the part.

Fig. 1.8. The stresses at a sharp change in the cross-section of the part, leading to brittle failure.

Many defects can be avoided by proper heat treatment procedures; sometimes giving a smooth finish to machined surfaces before welding and by providing a generous fillets (smooth curved surface) during welding avoids hot cracks in welding.



(*a*) (*b*)

Fig. 1.9. (*a*) *Hot cracks* (inter-crystalline cracks) in fillet weld (mild steel) (*b*) Hard zone crack in fillet weld (tensile steel).

Evaluative Questions

Q1. What is the importance of NDE (Non Destructive Evaluation) of surfaces and metallurgical structures and materials?

Q2. Is there any limitation of NDT (Non Destructive Testing)? If so, what?

Q3. List different methods of NDT. Which is the easiest and simplest of NDT? Which is the costliest method?

Q4. How is visual inspection carried out?

Q5. What do you mean by the term in-situ in "*in-situ*" metallography?

Q6. Explain the working of a metallurgical microscope. You may explain the different parts using a simple diagram.

Q7. What preparation of the surface is required before it is examined under a metallurgical microscope?

Q8. List the types of defects that can be examined by NDT methods.

Q9. Give some examples (of defects) that can be categorized as: (*i*) surface and sub-surface defects, and (*ii*) internal defects.

Q10. Why do cracks occur on the surfaces of parts and inside the metal?

Q11. The overall magnification of a metallurgical microscope that has an objective magnification of 30X and an eyepiece magnification of 10X is

(*a*) 3X
(*b*) 30X
(*c*) 300X
(*d*) 3000X

Q12. Identify which non-destructive techniques are capable of detecting

(*a*) only external flaws, and
(*b*) internal flaws.

Non-Destructive Testing

About the Book

Engineers and technical staff working in Manufacturing Industries, Process and Product Development Centres, R & D Laboratories, Testing, Standards and Certification/Inspection Agencies must have a good knowledge of the Non-Destructive Testing methods and processes for their professional growth and development.

Considering the importance of this subject, many universities and engineering colleges have introduced this subject either as a "Core" subject or as " an Elective" subject in their Mechanical Engineering Curriculum.

Also, an awareness must be created amongst Mechanical Engineering and Manufacturing Technology Students about the job opportunities available in Testing, Inspection and Quality Control Agencies and Certification Institutes and in related industries.

The Book has been developed for students who are preparing for their university examinations and for enhancing their professional knowledge and competencies in this area.

Contents

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- Eddy-Current Inspection
- Principle of Magnetic Testing or Magnetic Analysis Testing
- Acoustic Emission (A.E.)
- Non-Destructive Testing Methods
- Suitable Method of NDT

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Prof. M. Adithan has obtained his B.E. (Hons.) and M.Sc. Engineering from College of Engineering, Guindy University of Madras, and Ph.D. from I.I.T., Madras. He has worked for several years at I.I.T., Madras, NITTTR, Chandigarh and VIT University, Vellore (T.N.). He has also been a Visiting Professor at Brigham Young University, U.S.A. and at University of Technology, Malaysia. Presently he is Professor Emeritus at VIT University, Vellore, Tamil Nadu. He was also a UNESCO Fellow at Ohio State University, U.S.A.

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