MODERN ULTRASONIC TECHNIQUES FOR DEFECT DETECTION IN CAST MATERIALS

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INTRODUCTION

In casting flaw detection is exclusively concerned with manufacturing defects. The typical cast defects are (i) shrinkage cavities which form during solidification as a result of the reduction in volume when metal changes from the liquid to the solid state. Shrinkage cavities occur in situations where molten metal is not available to compensate for the volume decrease during solidification, (ii) porosity and gas holes; porosity is small smooth-faced cavities, generally smaller than 1.5 mm diameter, usually caused by the release of gas from the molten metal as it cools. Gas holes are also smooth-faced cavities but greater than 1.5 mm diameter. Typical causes of gas holes are evolution of gas from molten metal during solidifications, gas trapped as the molten metal enters the mould etc. (iii) hot tears; these are jagged crack type defects resulting from stresses imposed on the cast metal when it is just below the solidification temperature and so is in a weak condition. The stresses usually arise when the casting is restrained during contraction by the mould, or by an already solid thinner section. The defect occurs mainly at or near a change of section and may or may not extend to the surface, (iv) cracks; these are discontinuities due to the fracture of the metal during or after solidification, (v) inclusions; these are foreign non-metallic materials such as sand or slag trapped within the cast metal, (vi) cold shuts; these are basically 'lack of fusion' defect caused by the failure

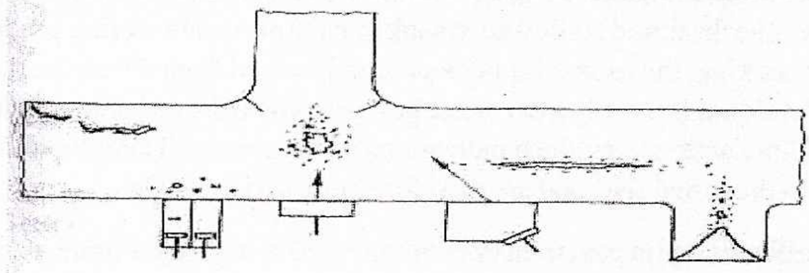

Fig. 1 : Typical casting defects and their detection methods by UT

of a stream of molten metal to form a continuous bond with a second stream, or solid metal such as an internal chill or splash. They are most prevalent in thin-walled castings. Various casting defects as described above are shown in Fig. 1[1].

At present liquid penetrant (LPI), magnetic particle inspection (MPI), x-ray radiography (RT) and ultrasonic (UT) testing are used in different areas of the casting industries. All these techniques are briefly described below[3].

VARIOUS NDT TECHNIQUES FOR DEFECT DETECTION IN CAST MATERIALS

Liquid Penetrant Inspection (LPI)

Liquid (or dye) penetrant inspection is an extension of visual inspection and is used for detecting surface-breaking flaws, such as cracks, laps and folds, on any non-absorbent material's surface.

The various stages of LPI are shown in Fig. 2. In this technique, the surface to be inspected is cleaned thoroughly to remove dirt and grease. A brightly coloured or fluorescent liquid is then

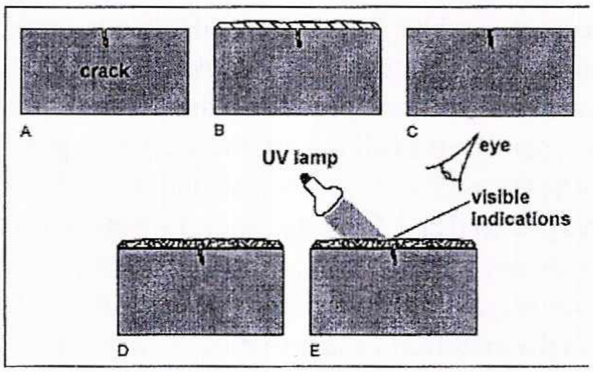

Fig. 2 : Various stages of Penetrant testing: (A) Sample before testing; (B) Liquid penetrant applied; (C) Surplus wiped off leaving penetrant in crack; (D) Developer powder applied, dye soaks into powder; (E) View coloured indications, or UV lamp shows up fluorescent indications

applied liberally to the component surface and allowed to penetrate any surface-breaking cracks or cavities. The time the liquid is allowed to soak into the material's surface is normally about 20 minutes. After soaking, the excess liquid penetrant is wiped from the surface and a developer applied. The developer is usually a dry white powder, which draws penetrant out of any cracks by reverse capillary action to produce indications on the surface. These (coloured) indications are broader than the actual flaw and are therefore more easily visible.

A number of different liquid penetrant systems are used in industry. Fluorescent penetrants are normally used when the maximum flaw sensitivity is required. In cast materials LPI is used to detect defects like hot tears, stress cracks, cold shuts etc.

Magnetic Particle Inspection (MPI)

Magnetic particle inspection (MPI) is used for the detection of surface and near-surface flaws in ferromagnetic materials. A magnetic field is applied to the specimen, either locally or overall, using a permanent magnet or electromagnet. If the material is flawless, most of the magnetic flux is concentrated below the material's surface. However, if a flaw is present, such that it interacts with the magnetic field, the flux is distorted locally and 'leaks' from the surface of the specimen in the region of the flaw. Fine magnetic particles, applied to the surface of the specimen, are attracted to the area of flux leakage, creating a visible indication of the flaw. The materials commonly used for this purpose are black iron particles and red or yellow iron oxides. In some cases, the iron particles are coated with a fluorescent material enabling them to be viewed under a UV lamp in darkened conditions (Fig. 3). MPI is used to detect defects like hot tears, stress cracks, cold shuts etc. in ferromagnetic cast materials.

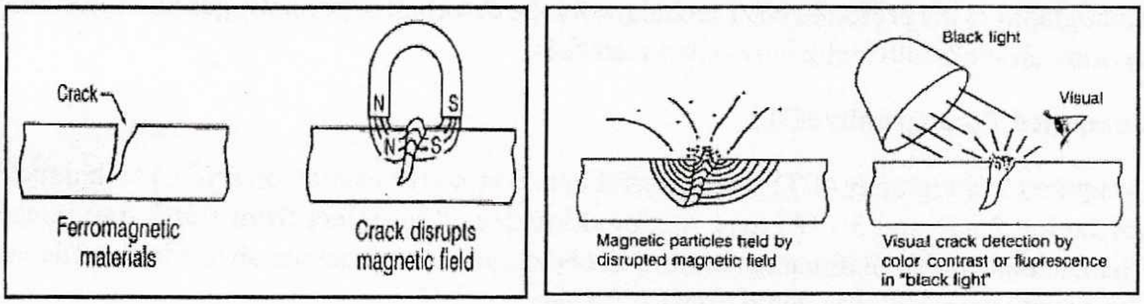

Fig. 3 : Principle of Magnetic Particle Inspection (MPI)

Radiography Testing (RT)

Radiography is the technique of obtaining a shadow image of a solid using penetrating radiation such as X-rays or gamma rays. This technique involves the use of penetrating gamma or X-

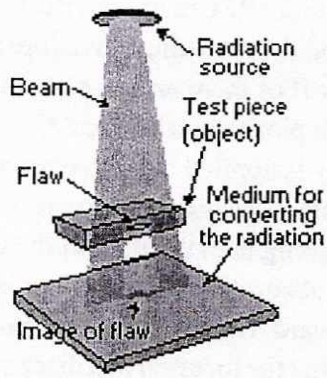

Fig. 4 : Principle of producing shadowgraph of objects using RT

radiation to examine parts and products for imperfections. An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal soundness of the part (Fig. 4). Possible imperfections are indicated as density changes in the film in the same manner as X-ray shows broken bones[4].

Radiographic applications fall into two distinct categories: (i) evaluation of material properties and (ii) evaluation of manufacturing and assembly properties. Material property evaluation includes the determination of composition, density, uniformity, and cell or particle size. Manufacturing and assembly property evaluation is normally concerned with dimensions, flaws (voids, inclusions, and cracks), bond integrity (welds, brazes, etc.), and verification of proper assembly of component pieces.

Radiography is the preferred NDT technique for the detection of porosity, gas holes, shrinkage cavities, air locks and inclusions in cast materials.

Computed Tomography (CT)

Computed Tomography (CT) is a powerful non-destructive evaluation (NDE) technique for producing 2 - D and 3 - D cross-sectional images of an object from flat X-ray images. Characteristics of the internal structure of an object such as dimensions, shape, internal defects, and density are readily available from CT images.

Ultrasonic Testing (UT)

Ultrasonic technique utilizes frequency of sound waves beyond human hearing (>20kHz) as a beam of illumination and measures the reflected beams from defects, inhomogeneities or the back wall of the test material. UT is the most widely used NDT technique in industries for product quality control compared to any other NDT methods. Basically, ultrasonic waves are emitted from a transducer into an object and the returning waves are analyzed. If an impurity or a crack is present, the sound will bounce off of them and be seen in the returned signal. A transducer made of a crystalline material with piezoelectric properties, such as quartz is used to generate ultrasonic waves. When electricity is applied to piezoelectric materials, they begin to vibrate, using the electrical energy to create movement. The waves travel in every direction from the source. To keep the waves from going backwards into the transducer and interfering with its reception of returning waves, an absorptive material is layered behind the crystal. Thus, the ultrasound waves only travel outward. Ultrasonic measurements can be used to determine the thickness of materials and determine the location of a discontinuity within a part or structure by accurately measuring the time required for an ultrasonic pulse to travel through the material and reflect from the back surface or the discontinuity. When the mechanical sound energy comes back to the transducer, it is converted into electrical energy. Just as the piezoelectric crystal converted electrical energy into sound energy, it can also do reverse. The mechanical vibration in the material couple to the piezoelectric crystal, which is in turn, generates electrical current.

In pulse-echo (P/E) mode of ultrasonic testing, single transducer is used as transmitter as well as receiver, which is placed on the test material. A good couplant (oil, water, vaseline etc) is required for proper coupling between the transducer and test material. A pulser is used to send electrical pulse to the transducer. The priciple of operation of ultrasonic system in P/E mode is shown in Fig. 5.

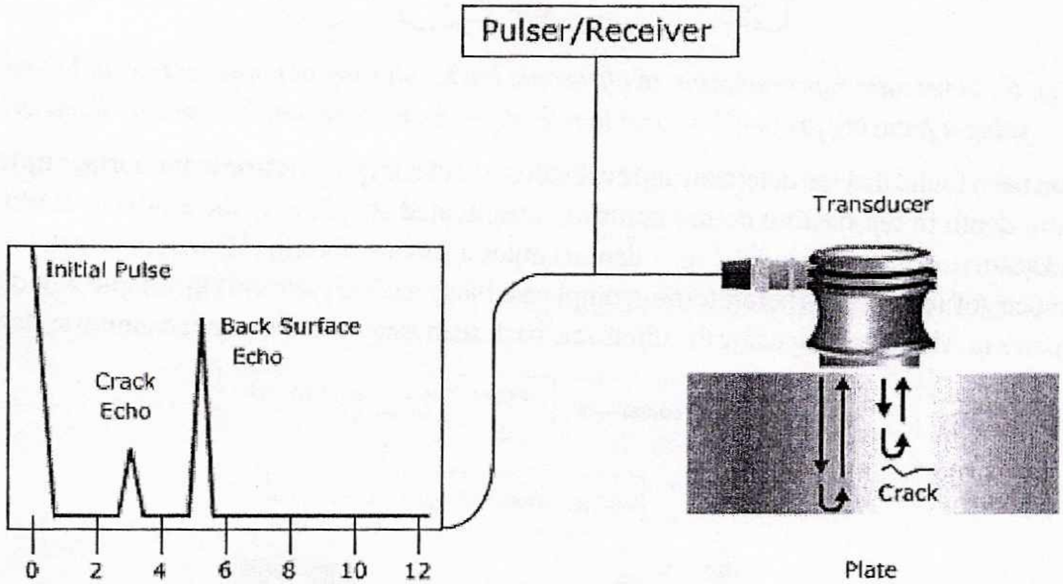

Fig. 5 : Principle of ultrasonic testing in Pulse-Echo mode

In cast materials, ultrasonic can be used to detect porosity, gas holes, shrinkage cavities, air locks and inclusions with proper selection of frequency because of the coarser grain size. Coarse grains give rise to scattering of signals, which in turn highly attenuates the signal[5]. Hence, for very coarse castings conventional ultrasonic testing is not suitable.

Modern approach in ultrasonic

Scattering of ultrasound at grain and phase boundaries in polycrystalline multiphase and/or porous materials causes attenuation and dispersive sound velocities. High-frequency ultrasonic backscattering signals are presently being explored for materials characterization and for the detection and evaluation of defects. Fig. 6 shows a schematic sketch of ultrasonic backscattering at pores and grain boundaries using a focusing probe. Porosity or single pores can only be detected when their scattering signals do not vanish within the background signal of the grain noise[6, 7].

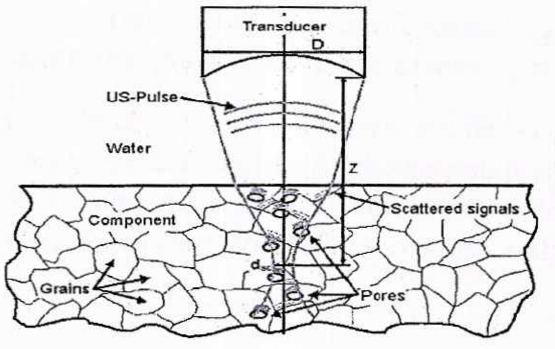

Fig. 6 : Schematic representation of ultrasonic backscattering at pores and grain boundaries using a focusing probe (Z = focal length, d_{SC} = focus diameter, D = probe diameter).

It has been found that the detection and evaluation of defects (pores) close to the surface up to about 2 mm depth in die-casting components of complicated shape, only the analysis of ultrasonic backscattering is promising[6]. Fig. 7 demonstrates a robot scanning UT system which learns the geometry of a component before testing complicated shapes of the parts and Fig. 8 depicts the detection of pores in Al dye casting using the ultrasonic back scattering with the same scanning system.

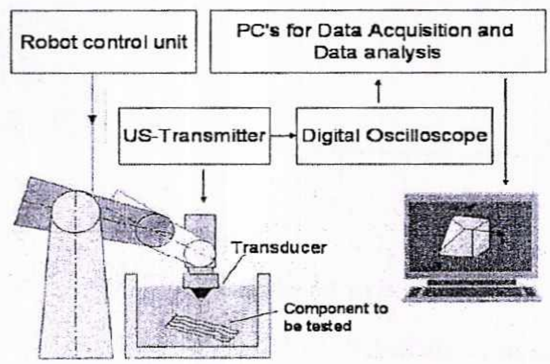

Fig. 7 : Robot controlled high frequency ultrasonic test system

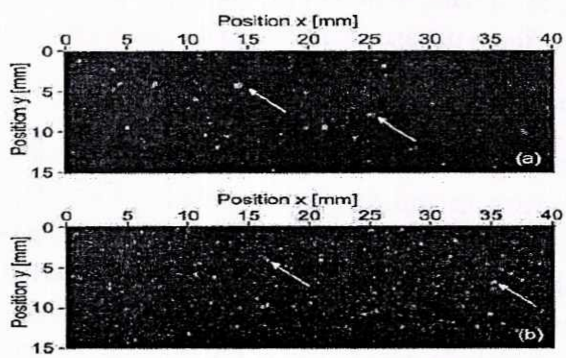

Fig. 8 : C-Scan of Al dye casting at a depth of (a) 0.5 mm and (b) 1 mm

CONCLUSION

This paper describes various NDT techniques used for defect detection in cast materials. It has also been shown that the recent approach to apply high frequency ultrasonic backscattering technique can overcome the limitations of conventional ultrasonic technique for very coarse casting in detecting small defects.

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