Ultrasonic Physics of Composite Materials

NILESH H. MANANI
Assistant Professor,
Physics Dept.
M. M. Science College, Morbi
Gujarat (India)

Abstract:
Composite materials consist of two or more elements, one of which, the fiber, is dispersed in a continuous matrix phase. The two elements work together to produce material properties that are different to the properties of the elements on their own. Composites offer the designer a combination of properties not available in traditional materials. It is possible to introduce the fibers in the polymer matrix at highly stressed regions in a certain position, direction and volume in order to obtain the maximum efficiency from the reinforcement, and then, within the same member to reduce the reinforcement to a minimal amount at regions of low stress value. Other advantages of composites are lightness, resistance to corrosion, resilience, translucency and greater efficiency in construction compared with the more conventional materials

Keywords: *Composite Materiels, Ultrasonic Inspection, Pulse Echo, Back-Scatter*

1. Introduction

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, racing car bodies, shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops.

2. Composite Materials

Concrete is the most common artificial composite material of all and typically consists of loose stones (aggregate) held with a matrix of cement. Concrete is an inexpensive material, and will not compress or shatter even under quite a large compressive force [citation needed]. However, concrete cannot survive tensile loading [citation needed](i.e., if stretched it will quickly break apart). Therefore, to give concrete the ability to resist being stretched, steel bars, which can resist high stretching forces, are often added to concrete to form reinforced concrete.

Fiber-reinforced polymers (FRP) s includes carbon-fiber-reinforced polymer (CFRP) and glass-reinforced plastic (GRP). If classified by matrix then there are thermoplastic composites, short fiber thermoplastics, long fiber thermoplastics or long fiber-reinforced thermoplastics. There are numerous thermo set composites, including paper composite panels. Many advanced thermo set polymer matrix systems usually incorporate agamid fiber and carbon fiber in an epoxy resin matrix.

Shape memory polymer composites are high-performance composites, formulated using fiber or fabric reinforcement and shape memory polymer resin as the matrix. Since a shape memory polymer resin is used as the matrix, these composites have the ability to be easily manipulated into various configurations when they are heated above their activation temperatures and will exhibit high strength and stiffness at lower temperatures[citation needed]. They can also be reheated and reshaped repeatedly without losing their material properties [citation needed]. These composites are ideal for applications such as lightweight, rigid, deployable structures; rapid manufacturing; and dynamic reinforcement.

3. Ultrasonic Inspection

Ultrasonic testing (UT) is the most widely used non-destructive inspection method for the examination of composites. On microscopically homogenous materials (i.e. non-composite) it is commonly used in the frequency range 20 kHz to 20 MHz With composite materials the testing range is significantly reduced because of the increased attenuation, so the operating frequency limit is usually 5 MHz or less. However, the ability to resolve small flaws will also be reduced and this must be borne in mind.

In most techniques short pulses of ultrasound (typically a few microseconds) are passed into the composite material and detected after having interrogated the structure. The techniques include *pulse-echo, through-transmission, back-scattering, acousto-ultrasonics* and *ultrasonic spectroscopy*. In these methods it is important to avoid frequencies at which resonance occurs between ply interfaces. For unidirectional plies spaced at 8 plies/mm this frequency is usually about 12 MHz. There may be an additional resonance for woven fabrics at approximately 6 MHz for 0.25mm plies, although resonance at other frequencies has been seen in practice.

In manual ultrasonic testing (UT) the area is contact-tested by scanning a probe by hand; this is suitable for fieldwork, provided the inspection area is small. Manual UT requires a high level of operator skill to get consistent results because the signal amplitude is dependent on the thickness of the coupling fluid layer, which itself is dependent on the pressure applied. However, provided a recognized calibration procedure is carried out, variations between properly trained operators should not pose a problem. For some composites that are water-sensitive or absorbent, the use of roller probes with water retentive rubber tires are preferred as they leave the surface dry. However, these operate at the lower end of the UT frequency range and therefore are not best suited to detailed defect characterization.

These examples of contact testing illustrate that the probe-specimen distance must be maintained within a narrow tolerance (typically less than a millimeter) otherwise the ultrasound transmitter will become de-coupled from the specimen.

By contrast, in non-contact ultrasonic testing, significant probe movements can be tolerated without de-coupling the transmitter. One way of doing this is by generating the ultrasound with a laser. This has the added advantage of speed and that the signal can be generated and detected in any orientation up to 60 degrees relative to the specimen. The technique is presently exploited commercially, e.g. the Laser Ultrasonic Inspection System (LUIS) developed by Ultra Optec. However, this approach is obviously relatively expensive and there is the risk of surface ablation and the physical safety measures required when using high powered lasers can be restrictive in a production or field environment. Another alternative is to use magnetostrictive transducers but these operate only at the lower end of the ultrasonic frequency range (200 kHz or less).

A more practical solution, known as immersion testing, or IUT, is to maintain a continuous column (preserved when the specimen probe distance changes significantly) of coupling fluid (usually water) between the probe and the specimen. When the specimen is small enough, an immersion test can be implemented by conducting the test with the probe and specimen completely submerged in coupling fluid. However, when the specimen is very large submersion is impractical because of the excessive cost and size of immersion tanks. Another problem is that if the specimen is buoyant, large forces are needed to keep it submerged. An alternative to submersion is the jet probe technique in which the ultrasound is coupled by a water jet applied by two specially designed probes, one transmitter and one receiver. This propagates the ultrasound along a narrow column of water, which is constantly projected onto the specimen surface. This is much more tolerant of changes in surface contours and is clearly a more practical solution for large or highly buoyant specimens.

4. Pulse Echo

Ultrasonic pulse-echo is a well-established and widely used non-destructive testing technique. A pulse of ultrasonic energy, typically a few microseconds, is transmitted into the specimen in a direction normal to the surface. The pulse is reflected from good matrix- Reinforcement boundaries and also from boundaries associated with flaws. Figure 1 shows a typical pulse-echo set-up for a submerged immersion test.

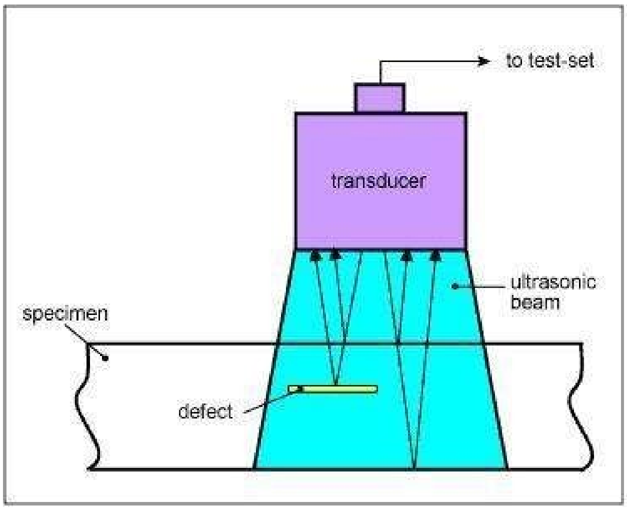

Figure: 1

Those signals which travel back towards the probe are detected and the position and size of a flaw is determined from the total pulse travel time and detected amplitude respectively. This is the 'A-scan' display and it consists of a series of peaks, the position of which along the horizontal axis can be calibrated in terms of the depth in the composite. The amplitude of each echo will give some indication of the size and nature of the reflector, which might be a flaw or a specimen boundary.

Figure 2 shows a typical A-scan display from a pulse-echo immersion test. In this display, the echoes from different features within the composite do not merge (i.e. they are well resolved) because the pulse duration is short to avoid it interacting with any of the features at the same time.

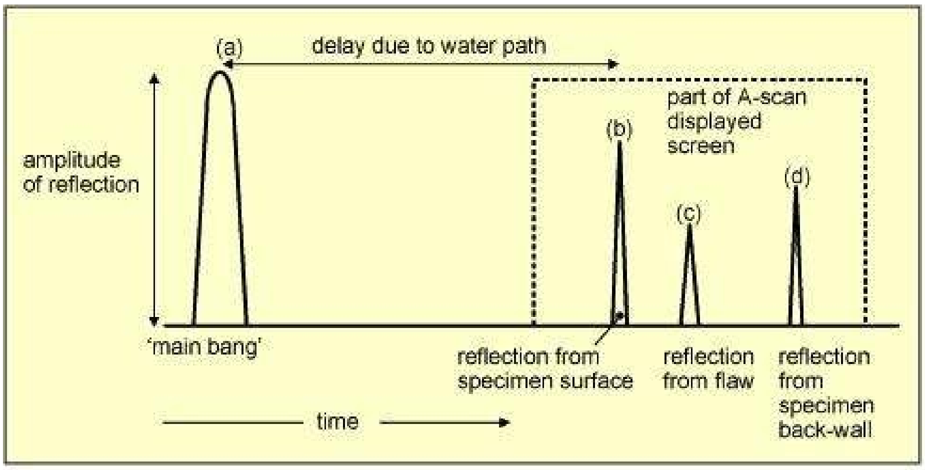

Figure 2

The first peak (a) is due to the electrical pulse used to excite the transducer (also called the 'main bang') and is a convenient reference for the following peaks. These are the front surface of the component (b), a flaw (c); and the rear surface of the component also known as the back-wall (d).

5. Back-Scatter

Fiber orientations and their stacking order determine the final product properties. In its most common configuration, back-scatter is a variation on pulse-echo in which the transducer is inclined at an acute α, to the normal to the test structure surface. The echoes received by the transducer are monitored as the component or transducer is rotated about an axis normal to the component surface, the angle α being kept constant. Figure 3 shows a typical back-scatter set-up.

When the angle of rotation, β is such that the transducer is normal to the fiber direction in any of the layers of the structure, the back-scattered signal reaches a maximum. A plot of the signal intensity versus the angle of rotation is recorded.

The method can also be applied with a variable angle α or with separate transmitting and receiving transducers located on opposite sides of the specimen.

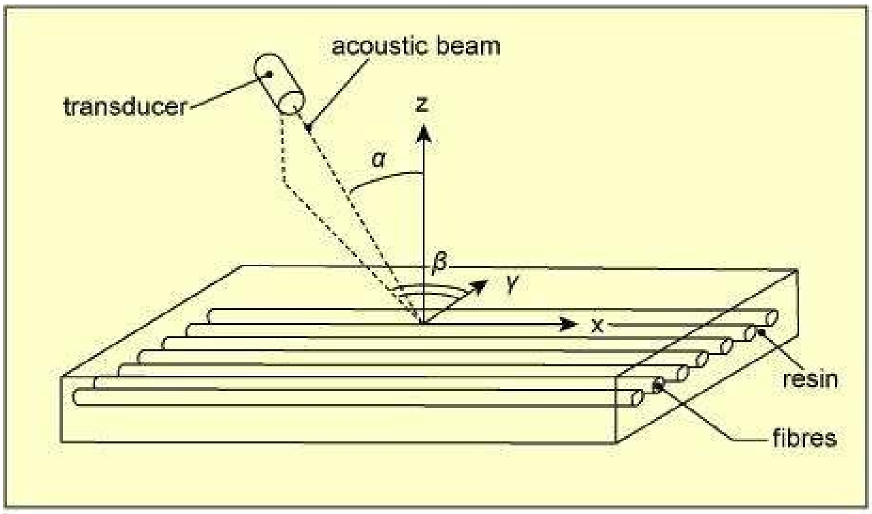

Figure 3

This technique may be used to check the stacking sequence. For example, the fiber orientation of graphite epoxy laminates in several lay-ups is easily resolved. It can also detect porosity because if it is present, the back-scattered signal is higher at all angles of rotation compared with a sound specimen. However, surface roughness produces a similar effect, so it may be necessary to smooth the surface before testing. This technique will also detect local fiber waviness, ply-end discontinuities and trans-laminar cracks. It can also be used to detect matrix cracks due to thermoplastic stress.

References

1. Damage and its Evolution in Fiber - Composite Materials: Simulation and Non- Destructive Evaluation ISBN: 3930683903 October 2006 Language: English Editors: Gerd Busse, Bernd-H. Kröplin, Falk K. Wittel Universität Stuttgart 548 Pages incl. 94 color illustrations
2. Non-Destructive Testing of Fiber-Reinforced Plastics Composites ISBN1851660933 AUTHOR edited by J. Summerscales, Advanced Composites Manufacturing Centre, Plymouth FORMAT, Hardbound, 278 pages PUBLISHER Kluwer Academic Publishers, September 1987
3. Nondestructive Characterization of Composite Media ISBN0877629250 AUTHOR Ronald A. Kline PUBLISHER Technomic Publishing Co., 1992
4. Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil

Infrastructure, and Homeland Security 2007 (Proceedings of SPIE) (Paperback) by H. Felix Wu (Author) ISBN-10: 0819466522

5. Composite Materials: Properties, Non-Destructive Testing, and Repair Vol 1 by M.M. Schwartz (Author) ISBN-10: 0133000478 Publisher: Prentice-Hall (30 Jul 1997)