Destructive testing methods of welded joints

This chapter describes three important destructive testing methods of welded joints namely toughness test, fatigue test and fracture toughness testing. Additionally, concept of fracture toughness and conditions required for fracture toughness test for different stress conditions has also been presented. Further, non-destructive testing methods have also been presented.

Keywords: Impact test, Izod and Charpy test, fatigue test, endurance limit, fracture toughness, plain strain condition, CT specimen, three point bending specimen, Dye penetrant test, magnetic particle test, eddy current test and ultrasonic test

32.1 Toughness testing

In actual practice, engineering components during service are invariably subjected to various kinds of loads namely static and dynamic loads which are classified on the basis of the rate of change in magnitude of load and direction. Dynamic loads are characterized by high rate of change in load magnitude and direction. Reverse happens in case of static loads. In the hardness test and tensile tests, load is increased very slowly that corresponds to the behaviour of material under more or less static loading condition. Moreover, very wide range rate of loading (0.0001 to 1000mm/min) can be used in tensile test. Rate of loading governs the strain rate and so rate of hardening which can affect mechanical behavior of material. For example, material at low rate of loading showing the ductile behaviour can exhibit brittle behaviour under high rate of loading conditions.

The toughness test simulates service conditions often encountered by components of the system used in transportation, agricultural, and construction equipment. A material high impact resistance is said to be a tough material. Toughness is the ability of a material to resist both fracture and deformation. Toughness is the combination of strength and ductility. To be tough, a material must exhibit both fairly good strength and ductility to resist cracking and deformation under impact loading. Notches are made intentionally in impact test specimens to increase the stress concentration so as to increase tendency to fracture as most of the mechanical components have stress raisers. To withstand an impact force, a notched material must be tough.

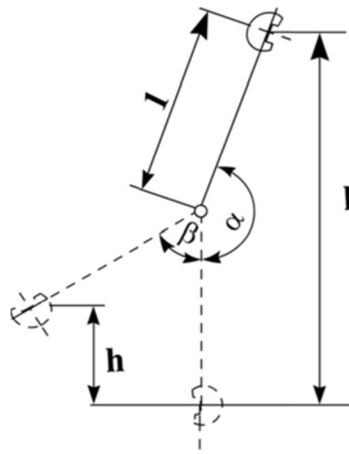


Fig. 32.1 Principle diagram of toughness test.

To study the behaviour of material under dynamic load conditions (at high rate of loading) toughness test is frequently conducted. There are two methods used for toughness testing namely Izod and Charpy test, based on the common principle of applying the load at high rate and measuring the amount of energy absorbed (kg m or Joule) in breaking the sample due to impact (Fig. 32.1). However, there are some differences also in these two methods in terms of sample size and shape, method of holding of the sample and maximum energy content of pendulum that hits the sample during the test.

Sr. No.	Toughness test	Sample	Holding
1	Izod	Held vertically on anvil as cantilever	Cantilever type and notch faces the pendulum
2	Charpy	Held horizontally on anvil as simply supported beam	Simply supported type and notch is opposite side of pendulum impact (not facing to pendulum)

Standard sample for both testing methods having a notch and is mounted on the machine in specific ways i.e. notch faces to pendulum in case Izod test while pendulum hits the sample from back of the notch in Charpy test (Fig. 32.2).

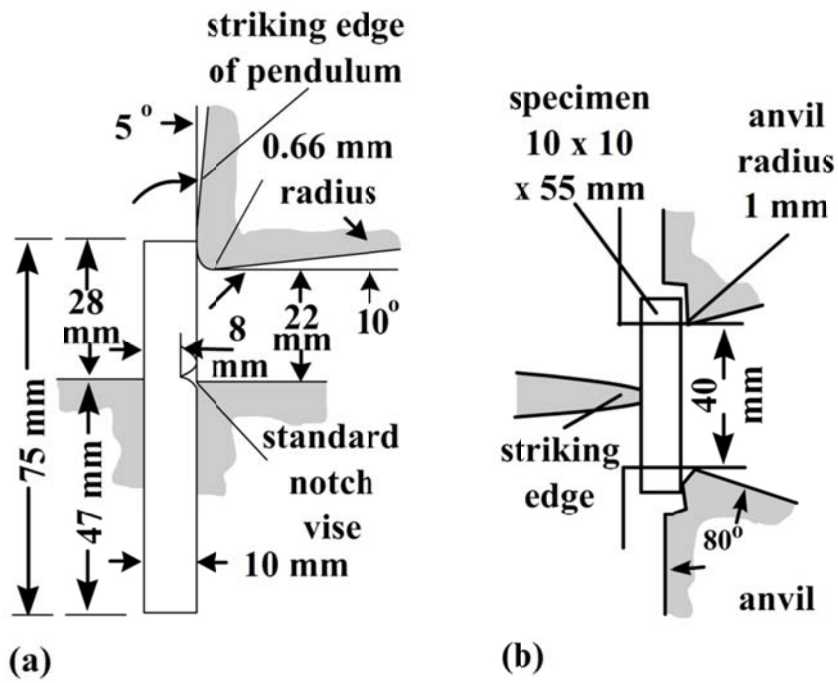


Fig. 32.2 Standard specimens for a) izod and b) charpy impact test

Since most of the engineering components are invariably designed with notch and stress raisers therefore, it becomes important to know about the behaviour of material with notch under impact loading. Hence, toughness test is usually conducted using sample with notch. Moreover, un-notched samples can also be used for the toughness test and the results are expressed accordingly.

Results of impact tests are expressed in terms of either amount of energy absorbed (Nm) or amount of energy absorbed per unit cross sectional area (Nm/cm^2) by standard sample. It may be noted that values of toughness are not directly used for design purpose but these only indicate the ability of the material to withstand against shock/impact load i.e. load applied at very high rate. These tests are useful for comparing the resistance to impact loading of different materials or the same material in different processing conditions such as heat treatment, procedure and mechanical working etc. Resistance to the impact loading of a material appreciably depends on the surrounding temperature (Fig. 32.3). Therefore, temperature at which toughness test is conducted must be reported with results.

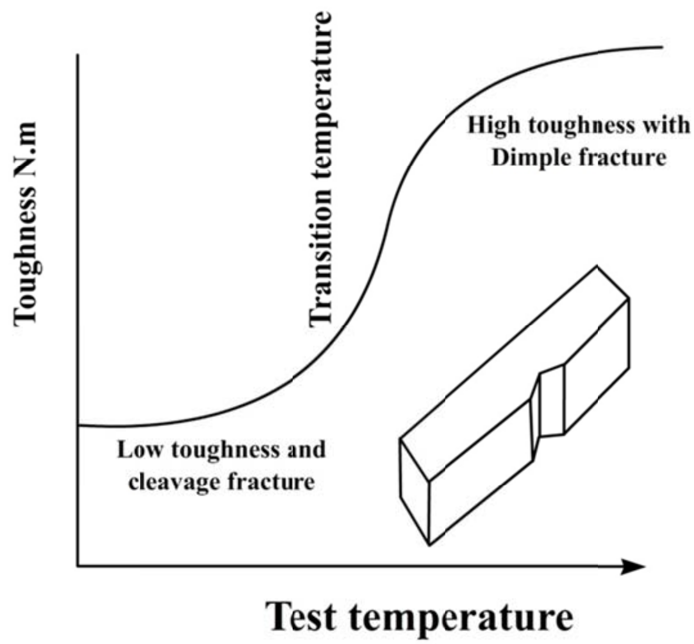
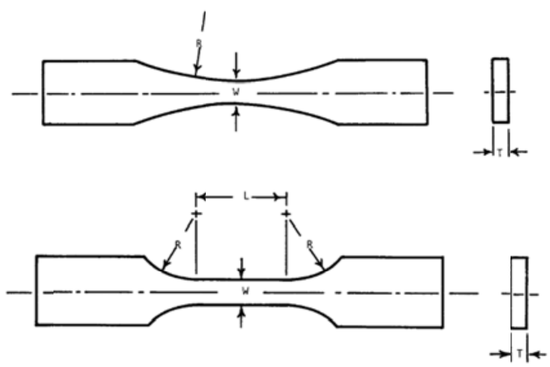


Fig. 32.3 Schematic diagram showing influence of test temperature on toughness

32.2 Fatigue behaviour of weld joint

The fatigue performance of the metallic components in general is determined in two ways a) endurance limit i.e. indicating the maximum stress, stress amplitude or stress range for infinite life (typically more than 20 million of load cycles) and b) number of load cycle a joint can be withstand for a set of loading conditions as desired. Two types of samples are generally prepared for fatigue studies as per ASTM 466 (Fig. 32.4 a, b). Reduced radius sample generally ensures fracture from weld joint or any specific location of interest (Fig. 32.5 a, b). The fatigue performance is appreciably influenced by the various variable related with fatigue test namely stress ratio, type of stress (tension-tension, reverse bending, tension-compression, zero-tension), maximum stress, stress range, loading frequency and surrounding environmental conditions such as temperature, corrosion, vacuum, tribological conditions. Each and every parameter to be used for the fatigue test must be carefully selected and recorded with results while reporting. The fatigue test results should include following.

- Test conducted according to ASTM E466 standard
- Type of loading: axial pulsating/reverse bending/tension-compression
- Maximum stress:
- Stress ratio (ratio of minimum stress to maximum stress)
- Temperature: ambient/vacuum/corrosion
- Frequency of pulsating load: load cycles per min
- Type of sample

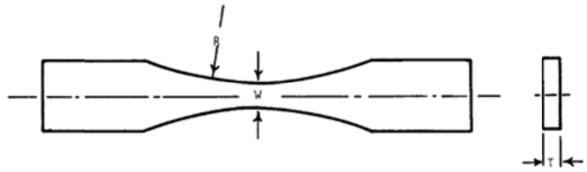


a) b)

Fig. 32.4 Standard specimen for fatigue testing

To conducting fatigue test, first step is conduct the tensile test on the weld joint for establishing the yielding strength of metal as maximum stress becomes 0.9 times of yield strength of material. For plotting the stress-number of cycle (S-N) curve, fatigue test is first conducted with maximum applied tensile load corresponding to 0.9 times of yield strength of weld joint under study to determine the number of load cycle required for fracture and then in the same way test is repeated at 0.85, 0.8, 0.75, 0.7 …. times of yield strength of weld joint until endurance limits or desired fatigue life is not achieved (Fig. 32.6). Typical dimensions of a standard specimen as per ASTM 466 are as-under.

- Continuous radius (R): 100mm
- Width (W): 10.3mm
- Thickness *T): 11mm (as received)
- Gripping length: 50mm



a)

b)

Fig. 32.5 Fatigue test sample a) Schematic diagram of standard fatigue test sample with continuous radius between ends and b) photograph of typical specimen

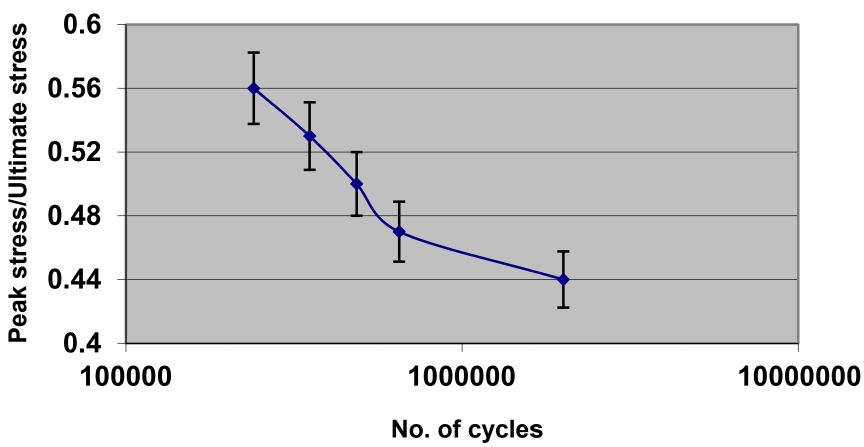
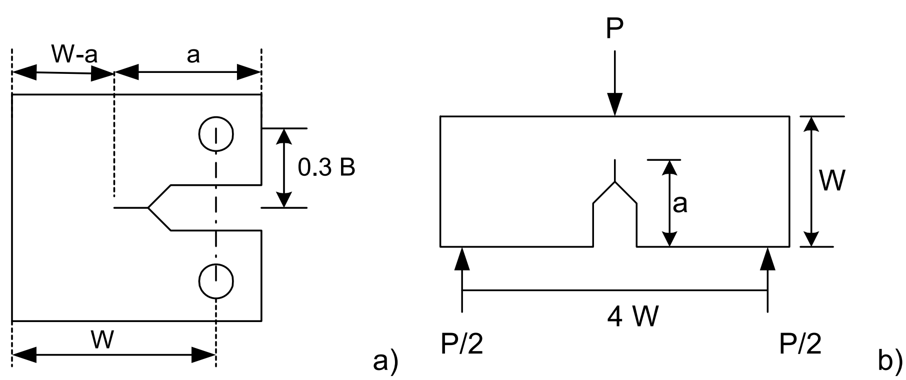


Fig. 32.6 Typical data on fatigue test showing peak stress/ultimate stress vs. number of cycle relationship for structure steel

32.3 Fracture toughness

The resistance to fracture conversely resistance to crack growth is known as fracture toughness and is measured using various parameters such as a) stress intensity around the crack tip (K), opening of crack mouth also called crack tip opening displacement (CTOD) and energy requirement for growth of crack (J or G). The mechanical properties namely yield strength and ductility and thickness of the weld joint under study primarily dictate the suitable parameter to be used for determining the fracture toughness. The fracture toughness parameter namely stress intensity factor (K) is commonly used for weld joint of heavy sections of high strength and low ductility material developing plain strain conditions, while crack tip opening tip displacement and energy based methods (G and J integral) are used for comparatively thinner sections made of low strength and high ductility material and those develop plain stress condition under external loading. Measurement of fracture toughness using any of above parameters is performed using two types of samples a) compact tension specimen (CT) and b) three point bending specimen (TPB). Schematics of two type of specimen are shown in Fig. 32.7. In general, in these tests, applied external load is increased until strain/crack opening displacement/energy vs. load relationship becomes non-linear. This critical value of load (P) is used for calculations of fracture toughness using relevant formulas.



W=2B, a=B, W-a=B and radius of hole r = 0.25B where B is plate thickness

Fig. 32.7 Schematic of fracture toughness specimens using a) compact tension and b) three point bending approaches

Although different standards have historically been published for determining K, CTOD and J-integral, the tests are very similar, and generally all three values can be established from one type of test.

In general, stress intensity factor (K) decreases with increase in specimen thickness. This trend continues up to a limit of thickness thereafter K becomes independent of the plate thickness. The corresponding value of K is called critical stress intensity factor (Kc) and occurs in *plane strain condition*. K_{IC} is used for the estimation of the critical stress need to apply to a specimen with a given crack length for catastrophic fracture to take place.

$$\sigma_C \leq K_{IC} /(Y(\pi\ a)^{1/2})$$

Where K_{IC} is the stress-intensity factor, measured in MPa*m½, σ_C is the critical stress applied to the specimen, a is the crack length for edge crack or half crack length for internal crack and Y is a geometry factor

32.4 Non-destructive testing (NDT)

To determine the presence of surface and surface imperfections, non-destructive testing of weld joints can be carried out using variety of techniques as per needs. Apart from the visual inspection, many non-destructive testing methods including dye penetrant test (DPT), magnetic particle test (MPT), eddy current test (ECT), ultrasonic test (UT), radiographic test (RT) etc. are used in manufacturing industry for assessing the soundness of weld joints. In following section, principle and capability of some non-destructive testing methods have been described.

32.4.1 Dye penetrant test

This is one of the simplest non-destructive testing methods primarily used for detecting the presence of surface defects only. In this method surface to be tested a thin low viscosity and low surface tension liquid containing suitable dye is applied (Fig. 32.8). The thin liquid penetrates (by capillary action) into fine cavities, pores and cracks, if any, present on the surface. Excess liquid present at surface is wiped out. Then suitable developer like talc or chalk powder is sprinkled over the surface. Developer sucks out thin liquid with dye wherever it is present inside the surface discontinuities present on the weld joints. Dye with liquid changes colour of developer and indicates location, and size of surface defects.

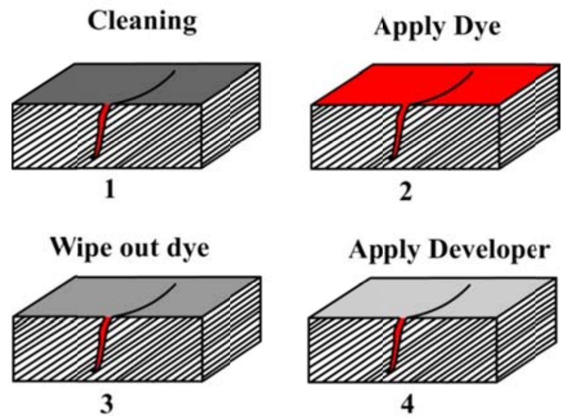


Fig. 32.8 Schematic showing four steps of dye penetrant test

32.4.2 Magnetic particle testing

This method is mainly used for assessing the surface and near surface defects in magnetic material. It is based on the simple principle of the flow of magnetic line of forces. Magnetic flux flows easily through metal from south to north-pole. The component to be evaluated is magnetized using electrical energy or suitable permanent magnetic. The electro-magnetization is performed using suitable yoke which is applied across the location / area to be tested. Presence of any dis-continuity in the form of crack, porosity, near surface defects in the path of flow of these lines results in leakage of magnetic flux forming two additional poles. The magnetic powder particles (in dry form or suspension form in thin liquid) are sprinkled over the surface of components to be tested. The magnetic particles tend to migrate toward the location wherever leakage of magnetic flux had taken place and then get piled up (Fig. 32.9). The particles align along discontinuities on the surface, near or shallow sub-surface discontinuities. The location and pattern of piled up magnetic powder particles suggest the location, size, type of discontinuity present on the surface or near surface region. Hazy pile of powder particle indicates the sub-surface defect. Formation of very thin line of powder particles suggests presence of crack with details of size and location of crack. However, this method of testing is found fit for ferromagnetic metal only.

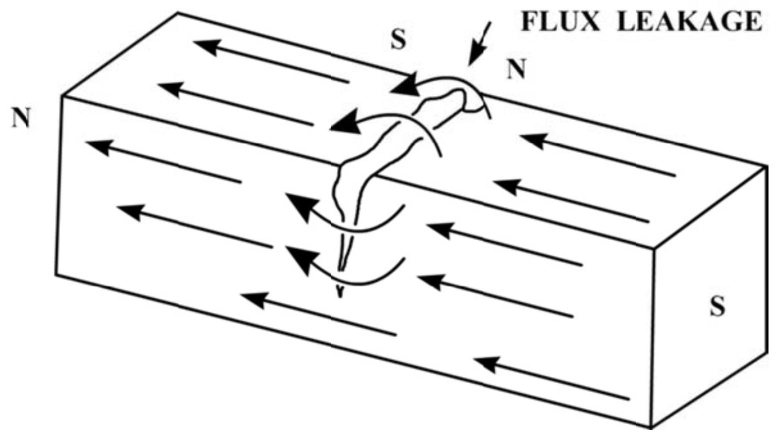


Fig. 32.9 Principle of magnetic particle test

32.4.3 Ultrasonic testing

This is one of the most popular, quick, cost effective and capable methods of NDT as it not only indicates the presence of discontinuities but also suggests their location using ultrasonic vibrations. Ultrasonic vibrations have capability to penetrate into the metals and are reflected as soon as they come across a change of medium e.g. metal to air, air to metal, metal to dis-continuities etc. This reflection characteristic of ultrasonic vibrations from the interfaces of change in medium is mainly exploited for detecting the presence or absence of discontinuities. Application of ultrasonic vibrations in a sound metal system at the sources produces two interfaces a) at top surface due to change of medium from air to metal and b) at the bottom surface due to change of medium from metal to air. The ultrasonic vibrations are used in two ways for NDT a) transmission and b) reflection of vibrations to evaluate the soundness of the weld joints in consideration. All these methods are very effective for parallel surface components e.g. plates, sheets.

Transmission approach

The transmission approach of ultrasonic testing uses two separate devices namely transmitter of vibration and receiver. Transmitting probe generates and sends the ultrasonic vibrations and receiver gets these vibrations at other end. Therefore, transmission approach needs access to both the sides of the components to be tested. Inputs from transmitting and receiving probes are given to oscilloscope (Fig. 32.10). Metal system without discontinuities shows the two peaks in oscilloscope i.e. one from the top surface and another from the bottom surface. In presence of discontinuity in the metal being tested, ultrasonic vibrations are reflected so they don't reach up to the receiving end and so no signal is received. Under this condition, only one peak in observed in the oscilloscope and absence of another peak from bottom surface suggests presence of discontinuity in the metal tested. One by one entire surface area of the component to be tested is scanned using transmitting and receiving probes. However, transmission approach is not very useful due to two reasons a) requirement of access to both sides of component to be tested and b) difficulty in placement of receiving probe in line of transmitting probe sending ultrasonic vibrations especially in case of components having thick sections.

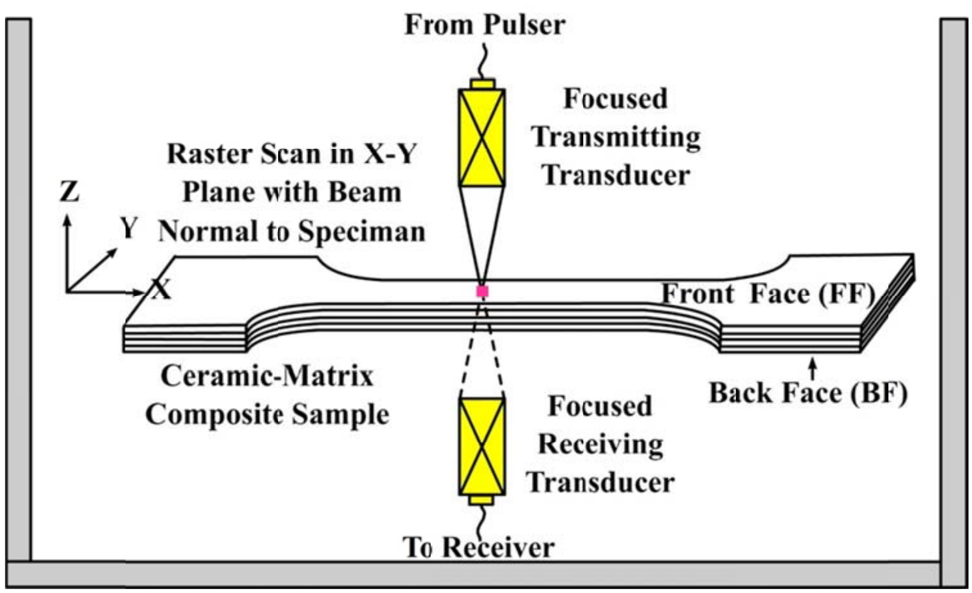


Fig. 32.10 Transmission type of ultrasonic testing

http://www.tms.org/pubs/journals/JOM/0301/Kim/Kim-0301.html

Reflection Approach

The reflection approach uses single probe which acts as a transmitter as well as receiver of ultrasonic vibrations. In metal system without discontinuities, application of ultrasonic vibrations results in the two peaks in oscilloscope i.e. one from the top surface and another from the bottom surface like transmission approach (Fig. 32.11). In presence of discontinuity in the metal being tested, ultrasonic vibrations are reflected. Vibrations reflected from the discontinuity shows additional peaks between the surface and bottom peaks in the oscilloscope. Relative location of the intermediate peaks (between the top and bottom surface peaks) suggests the distance of discontinuity from the surfaces. The reflection approach overcomes both limitations of transmission approach as it uses single probe so it does not require a) access of both sides of the component to be tested and b) alignment of transmission and receiving probes.

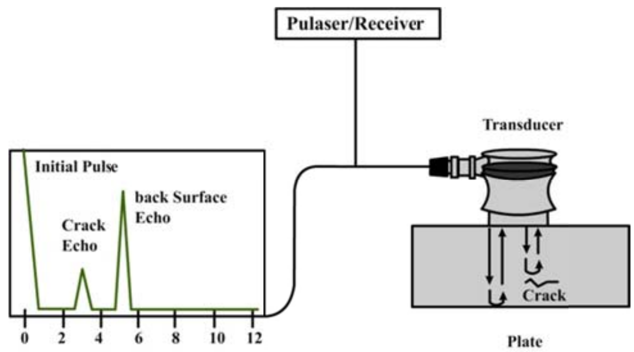


Fig. 32.11 Reflection type of ultrasonic testing

(http://ultrasonicinfo.blogspot.in/2007/11/basic-principles-of-ultrasonic-testing.html)

Pitch Catch method

In this method, ultrasonic vibrations are transmitted using 45 and 60 degree to the surface of the material to tested (Fig. 32.12). Reflected vibrations from the other reflecting surface or discontinuity are used to identify the presence and location of discontinuity in weld joints and other parallel sided surfaces.

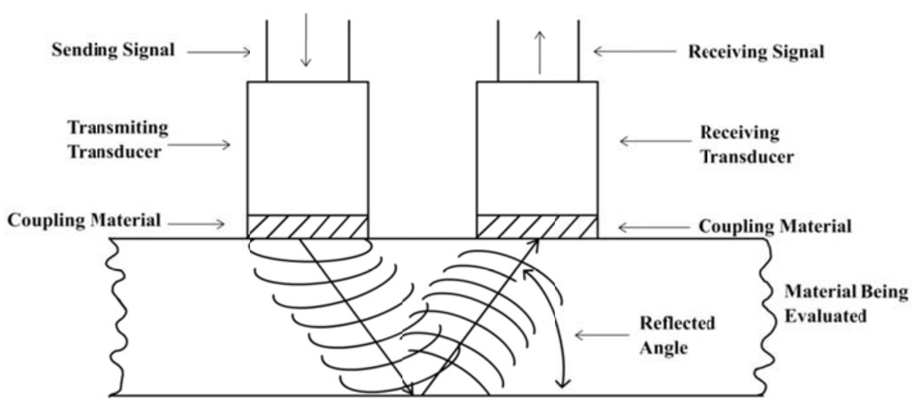


Fig. 32.12 Schematic of pitch catch method of ultrasonic testing

Coupler

For effective transmission of ultrasonic vibrations from the transmitting / source probe to the metal surface, generally a fluid mostly in the form of water or low viscosity liquid called coupler is used. The coupler ensures proper contact and transmission of vibration from source probe to metal surface with minimum losses. Water is considered as the best coupling media because it is readily available, low viscosity, and relatively safe to use with most construction materials. In the pitch-catch method, a water-based gel has proven to be the most practical coupling agent.

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