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Ultrasonic Testing For Determination Internal Flaws And Discontinuities In Metal Casting: A Review

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Abstract

In metal casting, UT plays a significant role in determining subsurface and internal fault identification. UT is closely related to the qualifying quality of metal cast objects. The quality of the cast item is directly related to the melting of the raw material, the pouring of molten metal, and the solidification. Surface flaws may be rectified using welding, grinding, or machining. However, due to the detrimental effects of radiation, ultrasonic testing is thought to be more efficient than x-ray at identifying internal defects. The only constraint with UT is determining the precise location of the problem. Because of the density of the material, law frequency probes can only be used to analyse metal casts. Flaws in side walls may be recognised rather consistently using high-frequency probes. In the aerospace sector, A-scan and C-scan in UT are precise for defect identification in aluminium alloys, magnesium content iron, carbon fibre reinforced polymer (CFRP), and glass fibre reinforced polymer (GFRP) materials. A smooth surface is necessary for ultrasonic testing so that the front wall echo is not disseminated. Low frequency probes can make Phased Array Ultrasonic Testing (PAUT) more efficient than the conventional multi probe approach.

Keywords: Ultrasonic testing (UT), Casting defect, Non-destructive testing (NDT), Phased array ultrasonic testing (PAUT)

Introduction

Manufacturing flaws in metal cast products occurred because of raw material used for melting, mould cavity design and preparation, component geometry, various procedures of melting and pouring molten metal, and solidification. Casting flaws are categorised into three primary categories: (i) mini or micro defects such as porosity, micro porosity, and gas holes, (ii) inclusion of sand, slag, and impurities, and (iii) line defects such as hot tears and shrinkage fractures[3].

Shrinkage cavities form when the volume of liquid metal reduces to a solid piece of metal during solidification in the absence of necessary molten metal. Porosity and gas holes are caused by gases expelled from liquid metal during solidification. Porosity is seen in holes smaller than 1.5mm in diameter, but gas holes can be bigger. Generally, gas holes have been barriers in the discharge of gases throughout the pouring process. Hot tears are sharp, abrasive, and jagged cracks caused by pressures. When the temperature of the metal falls during solidification, the metal contracts and is constrained at the mold's wall, forming hot tears. Similarly, fractures form during and after solidification. Impurities like as sand and slag, as well as nonmetallic particles in the environment, can lake of fusion is the cause of cold closes.

Visually discovered faults can be rectified, however flaws situated below the surface or internally that are not visible to the human eye can be identified using Non-Destructive Testing methods like as radiography, ultrasonic testing, and so on. In terms of safety precautions, radiography has highly negative and harmful impacts on human cells, which cause human illness. As a result, ultrasonic testing is the most effective NDT approach[27].

In UT, higher frequency sound waves more than 20KHz, which are beyond human hearing, were produced from a transducer on test material as beam illumination per unit area or volume, and the test material's front wall echo, rear wall echo, and defect echo were evaluated. In industries, UT is the preferred NDT technique[23]. Any fault, defect, cracking, inclusions, impurities, or existing sound waves that are going to bounce off the return imply that there will be one more echo before the rear wall echo. Ultrasonic waves are generated by crystalline piezoelectric materials such as quartz, which are utilised to build transducers. When electricity is applied to piezoelectric metal, it begins to vibrate to produce movement.

Ultrasonic echoes can freely move or travel in any direction from the source, allowing waves to interfere with their reception in the transducer, a stratum of an absorbent substance positioned behind the crystal. As a result, ultrasonic echoes pass through the substance and are returned to the transducer[1].

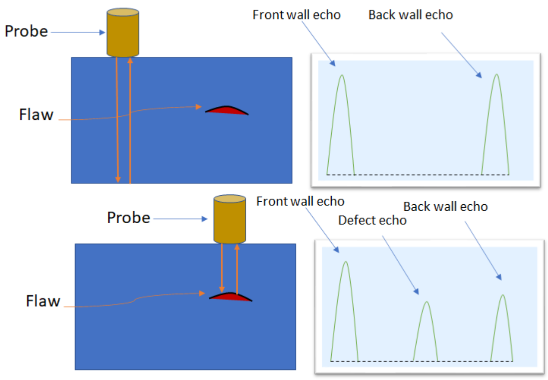

Figure 1 Method of ultrasonic testing

UT is used to falsify metal thickness as well as to identify and localise flaws inside metal. UT effectively measures the time it takes for a pulse to pass through an item and reverse from the rear surface or a defect or discontinuity. The transducer turns the incoming pulse into electrical output in the same manner as the piezoelectric crystal converts electrical energy into ultrasonic echoes[1].

In phase array ultrasonic testing, a single transducer serves as both transmitter and receiver and is positioned on the test metal[26]. Any viscous fluid, such as oil or water, can serve as a coupling medium between the probe and the object. In pulse echo mode, probes received electrical pulses from a pulser travelling through the item produce various waveforms of casting flaws, as illustrated in Fig.

UT scans may be classified into three types based on probe location and results on the CRO screen. The scan technique has three modes: echoes, transmit, and reverse through test object.

A-Scan

The A-scan or amplitude mode produces a one-dimensional output for the test item. A-scan transmits and receives echoes with a single probe. As illustrated in the picture, waves reflect back from the defect or front and back surface on the vertical axis and distance or time on the horizontal axis of CRO. The vertical height of the echos on the Y-axis reflects the strength of the fault, while the depth penetration on the X-axis indicates the duration or distance of the flaw. Distance between defects or faults may be estimated by multiplying distance by the product of velocity and time.

The A-scan technique is primarily utilised in ultrasonic flaw detectors to identify the position and magnitude of defects[26].

B-Scan

Except for a few small differences, B-scan or Brightness mode produces two-dimensional output in a manner similar to A-scan. Instead of moving the B-scan probe, position it in a fixed spot such that the

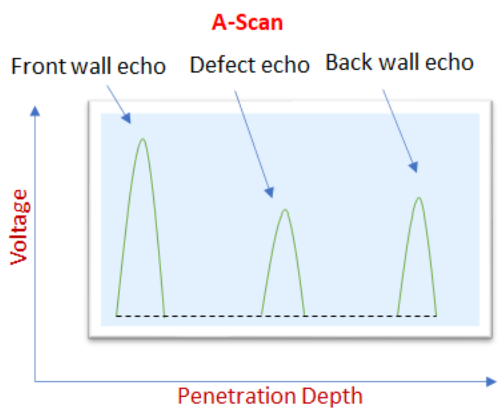

Figure 1.1 Method of A Scan UTechoes are displayed as dots on the CRO shown in the image[29].

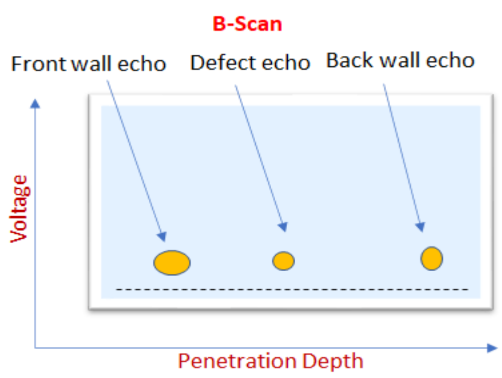

Figure 1.1 Method of B Scan UT

C-Scan

A time mode scan is used to detect flaws in an object's dynamic condition. C-scan is a mix of A-Scan and B-Scan features. T.M. Scan is in amplitude mode, with the probe stationary, and the output of echos presented as a number of dots in brightness mode[26].

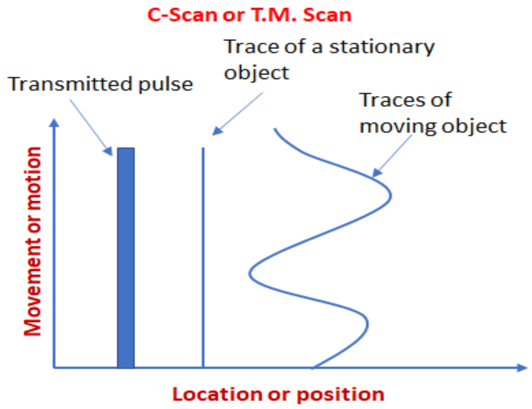

Figure 1.1 Method of C- Scan UT

The horizontal and vertical axes reflect dots at certain positions and motions of the test metal, respectively. As a result, as the test material moves, the points move at a slower rate. As a result, the test part in oscillatory motion is presented by tracing the line of the moving component, as illustrated in the figure above[26].

Literature Review

(1)In rough surface aluminium die casting, the most appropriate probe frequencies range from 5 MHz to 10 MHz, with surface roughness Ra values ranging between 50 m to 100 m of castings for inspection. It is still difficult to identify near-surface defects because the clustered front-wall echo produced from the rough surface castings mask is dispersed.

(2) This study presents novel ultrasonic techniques for producing quantitative 3D porosity profiles in resin layer thickness, ply spacing, and fibre orientation. These new technologies may have the ability to solve the NDT data analysis problem for composite aircraft. The tools are software-based and work by post-processing full-waveform data collected using one of many appropriate ultrasonic collection devices. Commercially available phased array systems are among them.

(3) Laser-EMAT (Electro Magnetic Acoustic Transducer) ultrasonics is a viable technology for on-line surface and interior flaw identification in a steel mill at temperatures above 700°C. The author claims that the work is extremely innovative, and the approach will go to the following phases, which will entail creating EMAT arrays and working on increasing the equipment's signal-to-noise ratio.

(4) At the foundry where ultrasonic assessment was performed, the magnesium concentration of liquid ductile iron dropped with time, from 0.07 percent Mg immediately after the conclusion of the spheroidization process to roughly 0.04 percent Mg after approximately 17 minutes. The entire time spent pouring the molten metal from the ladles was less than 20 minutes. The statistical analysis results show a linear relationship between the ultrasonic wave velocity and the graphite shape index, as well as the number of graphite precipitation of ductile iron made in the foundry where the

experiments were performed.As the graphite shape index and the quantity of graphite precipitations rise, so does the ultrasonic wave velocity.

(5)The study discusses the design of a testing machine for aerospace equipment as well as the benefits of attaching a mechanized robot to a CFRP inspection work. Capable robots for testing during transmission, in pulse echo mode, and compatible with newly established coupling mechanics result in a very adaptable and strong robot. The best option for the aerospace sector may be GE sensing and inspection technology robotic to provide a superior solution.

(6) Ten Al casting samples were made, each with a different pouring rate. They were then examined using the Penetrant Test (PT) and the Ultrasonic Test (UT) to identify surface and subsurface flaws. Surface flaws were observed to rise substantially when the pouring rate was increased, as evidenced by penetrant testing findings. However, as ultrasonic testing revealed, when the pouring rate is increased, there are far fewer interior flaws.

(7) Ultrasonic Testing and Infrared Thermography are NDT methods used to evaluate the efficiency of in-service damages to complex surfaces such as wings or rods. An investigation indicates that an ultrasonic technique may be used to assess the depth of a flaw. Three NDT techniques are compared, as well as the practicality and time required to set up the experimental methodology. A wide variety of probes would be beneficial to discover any faults using Ultrasonic Testing. The relative cost would rise as the number of appropriate probes increased. The benefit of Ultrasonic Testing over visual techniques is the ability to determine the depth of the defect and the degree of precision attained.

(8)Because of the increased use of composite materials in structural aircraft components, automated ultrasonic testing (UT) is being demanded not only for vast surface areas, but also for smaller and more complicated geometrical components. Aside from the economic benefit of automated testing over human testing, complete availability and documentation of findings in B- or C-scan format is another advantage of automated testing. The use of a phased array in full parallel mode provides extra benefits in terms of testing complicated components as well as adaptability. This article discusses the incremental testing capabilities of advanced Phased Array technology compared to conventional testing, as well as its application into production-type aircraft testing equipment. In addition to testing capabilities, automated defect evaluation techniques are presented. Furthermore, industrial scanners are offered in both bespoke design solutions and the usage of conventional industrial robots. The growing usage of carbon fibre composites in aircraft design and manufacturing is a result of the requirement for automated, application-specific sensor and sensor head systems, as well as matching scanning-system solutions. Parallel B-scan phased array technology improves testing efficiency and simplifies automated testing solutions for complicated geometries.

(9)The UT technique (as defined by ASTM standard B548-76) may detect subsurface and internal discontinuities in samples manufactured using the third manufacturing process. The fourth manufacturing process did not reveal anything. The surface quality and form of the samples are critical for UT, since a smoother surface and a less complicated shape can provide more desirable findings. 3D picture of an optical microscope approach used to estimate the depth of open surface porosity. However, the depth of the majority of the observed porosities was unknown.

(10)Stress and residual stress are assessed using pulse eddy current (PEC) and ultrasonic testing (UT), however both procedures are inaccurate. However, data fusion is used to overcome obstacles, resulting in effective performance. Simulated strains in an aluminium alloy 2024 specimen, followed by acquisition and processing of PEC and UT signals linked to stresses. The useful information acquired is fused using an artificial neural network technique, and the fused data is utilised to estimate stresses. Significant improvement in measurement reliability and accuracy realised by neural network integration of PEC and UT data in stress measurement application.

(11)Using ultrasonic technology, investigate cold cracks in large steel items. (1) Ultrasound frequencies of 22 kHz and electric power of up to 300 watts have been tested. (2) Ultrasonic frequency of 22 kHz, pulse duration of 0.1s, and electrical power of up to 2000 W. The inefficiency of the ultrasonic input into the metal, which does not give the required temperature signals in the fracture zone. Ultrasonic research should be carried out indefinitely. More study is required to improve the frequency ranges for the ultrasonic input to the metal as well as the selection of an efficient inductor shape.

(12) Defect identification utilising ultrasonic C-scan inspection of electron beam melted additively manufactured Ti-6Al-4V parts at low frequencies, 2.2 MHz, 5 MHz, and 10 MHz, with 10 MHz demonstrating the capacity to identify defects through side surface with minimal relative error. Future work in this area might include increasing the frequency of inspections or testing more complicated geometries. Milled surfaces, as well as those parallel to the construction direction, generate data that may be used to discover defects at low frequencies.

(13)Single crystal Ni-based superalloy's gain structure defect detection done using combination of resonant ultrasound spectroscopy (RUS) and finite element analysis (FEA) models of resonance. Resonant ultrasound spectroscopy demonstrates the potential of nondestructive evaluation (NDE) with shot peened and heat treated recryllized Mar-M247 single crystals experiments. The influence of recrystallization on resonance may be separated and quantified using FE models with self-consistent elastic characteristics and varied recrystallization depths. The verified FE modelling framework is then applied to a turbine blade model to investigate RUS as a nondestructive evaluation approach for grain structure flaws in complicated geometry components. RUS is also extended to assess flaws, anomalies, and damage processes relevant to manufacturing process control and component lifecycle management.

(14)Ultrasonic nondestructive testing of spot welding demonstrates a relationship between welding microhardness and ultrasonic attenuation coefficient. Perfect welds were more difficult to achieve than bad welds. The weld nugget's cast microstructure features coarse granules. As a result, it has a significant ultrasonic attenuation. The microstructure is fine-grained and there is no melting. As a result, the ultrasonic attenuation is extremely low.

(15) Aluminium castings used for defects detection such as blow hole, cracks etc. to increse age of the component or breakage of the part. Suitable automation in UT or X-ray not available so new method of non-destructive testing and defect determination needs to be developed where in the process can be reliable, repeatable and also economical. Performance frequency response method creats vibration response of the casting shell to be tested by striking a brass tong on the shell at

different intensity. Peak acceleration, displacement and frequency of the holding pad recorded to detect the casting defect of porosity or blow holes without destruction. Method determine the acceptance zone and rejectance zone of castings, presence of blow holes or cracks identified in aluminium and steel castings at very low cost.

(16) According to the results of a novel ultrasonic fatigue testing equipment that generates a biaxial proportional stress on a cast aluminium alloy, self-heating is more evident than during tension-compression ultrasonic testing. The stop criterion should be enhanced in future study to identify tiny cracks as well as the surface quality of the specimens.

(17) Parts of satellite launch vehicles (SLV) made of ultra-high-strength maraging steel of 250 grade were tested for stress-corrosion cracking using a multi probe UT. The most difficult duty is detecting missing and new weld flaws. According to the study, Phased Array Ultrasonic Testing (PAUT) is superior to standard multi probe testing and will improve detection by low frequency probes in the future.

(18) The paper provides an overview of the basic principles of non-destructive testing (NDT) techniques used in post-process inspection. Visual examination, liquid penetrant testing, magnetic particle testing, eddy current testing, ultrasonic testing, and radiography are among the procedures used. The applicability of these nondestructive testing (NDT) techniques in additive manufacturing (AM) and their appropriateness for detecting flaws in additively produced components are discussed. The sensitivity, as well as the benefits and drawbacks of each approach, are assessed. Ultrasonic testing has been proven to be a reliable NDT technique for in-situ and post-process defect detection of additively produced components.

(19) Pipes constructed of high density polyethylene and polyvinyl chloride were examined with a focus distance of 75 mm using UT 10 MHz. It is used to assess rail faults less than 0.8 mm in size as well as the quality of spot welds (nugget). UT is critical for identifying defects in CFRP, GFRP, and BVIDs. The test specimen has artificially created grooves and slots, as well as ultrasonic c-scans. Defects in rail heads are detected with 70° probes. 37° probes are used to identify flaws caused by bolt holes. The 0° probe is used to identify abnormalities in the head or foot (horizontal defects).

(20)Deep learning X-ray by vision and feature-based mapping system undetected rate of casting flaws detection is less than 4%, and precision detection of defects is greater than 96 percent, which may improve cast product quality and minimise cast product rejection rate.

(21)Detection of casting flaws automatically claims findings for defect detection utilising the GRIMA dataset of X-ray pictures using convolutional neural networks (CNN) to locate casting flaws in X-ray images (GDX-ray). The results demonstrate that there is a trade off between localization accuracy and inference time, with the Faster R-CNN (region-based convolutional neural network) models generating predictions significantly slower than the other models. The work describes the initial effort to detect a casting fault using a GDX-ray dataset.

(22)Three moulds, one each of slag and silica sand, and a mixture of the two, were utilised for casting with Sodium Silicate-CO2 method by metal A356 (Al-7.5% Si) alloy for ultrasonic inspection. GBF (granualated blast furnace) slag and sand moulds provide a superior surface quality and dimensional precision, according to the results. According to the NDE findings, the sand and slag mould cast product had a sound casting with no surface, subsurface, or internal flaws. In LPT and UT, a few surface and subsurface flaws were observed in sand castings. Finally, GBF slag mould lead to defect-free castings; hence, it may be utilised as a moulding material to create real-time components with simple or complicated geometries.

(23) Pure Al (99.85%) sand was cast using different parameters such as pouring temperature, duration, and so on, and their optimization was performed using the Auto-CAST simulation approach. Ultrasonic testing is utilised in specimens to discover subsurface flaws and porosity regions. When there is porosity in the casting, the height of the peaks is extremely tiny and they are closer together.

(24)When examining for corrosion in inaccessible areas such as pipe supports, it is advised to use a combination of two or more techniques. For severe, acute, pitting-type flaws, a reflection frequency of around 20 MHz should be utilised. That it is the only technique under consideration that can identify localised pitting. Higher frequencies aid in the reduction of feature reflection and the identification of minor flaws.

(25)This study on Non-destructive testing for testing of surface or internal flaws in metal, without destruct the product. Radiography, Magnetic Particle Crack Detection, Dye Penetrate Testing, Ultrasonic Flaw Detection, Eddy Current and Electro-Magnetic Testing techniques used. Radiography technique of NDT adopted to detect internal defects of Al6061 cast which is made by stir casting process which is mono and multi-heat treated about 450◦C and 600◦C in muffle furnace and hydraulically compressed. Process can be performed for detection of internal defects in ferrous, nonferrous, and other metals. Due to density of the metal absorption is high so in primary inspection almost every defect detected by the NDT. Secondary stage compressed cast product's SEM image scan is done, specimen structural change in bond strength and hardness rise recorded. Primary (NDT) inspected values and secondary (SEM) microstructure data comparison reflects grain structure and the bond strength. Cast specimen without defect formed by pouring of pure Al6061 alloy metal. NDT method used to examine the hot forming heat treated specimen properly all the internal stresses and defects removed. Multi heating treatment can increase hardness compared to mono heat treating. Varying in size and thickness is depending on temperature which can be simulated by 3D forming tool. Grain boundary thickness and particle size being minimal because of multi heat treated compressed Al6061metal. Minimize the particle size give rise in strain rate. Paper describes metal process applied in aerospace field application for light weight high strength components.

(26) In this investigation, an immersion focal ultrasonic probe was employed because it can strongly focus on ultrasonic sound pressure at a specific spot and detect extremely minute discontinuities. Furthermore, it disregards non-relevant indicators outside the focus length. In the impact zones, BW and R echoes vanish or change. This composite specimen was subjected to impact testing at various energy levels in order to generate three damaged regions. Because the glass/polyester specimen had a clear surface, an ideal picture of the specimen representing the region and edge of the affected areas was obtained using a digital scanner.This study used the MSE and PSNR formulae to evaluate NDT techniques for detecting impact damage in GFRP specimens. The MSE value was found to be greater for X-ray radiography, whereas the PSNR was higher for the ultrasonic C-scan technique. The results showed that ultrasonic C-scan is a better approach for detecting impact in GFRP materials. This technique paves the way for future research in this field to examine the accuracy of other NDT methods for other materials.

(27)The vacuum vessel (VV) welding of the China Fusion Engineering Test Reactor (CFETR) is tested using conventional UT and linear probes of phased array ultrasonic testing (PAUT) of austenitic stainless steel. An automated PAUT system with a dual matrix array probe has recently been designed and validated in ASIPP for comparing the detectable and real magnitude of fake faults.

(28) Because of the unavailability of the equipment, polarised shear waves have not yet been used to identify flaws such as cracks. EMAT (electromagnetic accoustic transducers) employ two orthogonal coils to concentrate two perpendicular and linearly polarised shear waves orthogonal in a metal. Following that, a three-dimensional FEA wavefield caused by the EMAT and its interactions with crack-like flaws of various sizes, locations, and orientations was generated. Study focused on the application of EMAT in a pulse echo system for metal thickness and crack type defect detection and derived improved potential to build technique of breadth measurement and crack detection using EMAT. EMAT's OCLC (orthogonal co located coils) identify cracks with depths of 0:3mm (0:2) or greater by generating shear waves parallel to the defect face and distinguishing maximum amplitude and signals recorded with both coils. Signal amplitude drop 2 at crack depth, thus amplitude drop cannot estimate defect size, but it can provide a reference location of OCLC EMAT relative to the linear or crack-like defect. There is a low likelihood of detection since OCLC EMAT is not on top of the stack and is not aligned with the fault direction. FEA study was performed for 0:05mm-width notches. For thickness measurements and crack-type defect identification, new NDT and traditional NDT are utilised effectively in one setup.

(29) In the identification of defects in magnesium alloy casting, phased array ultrasonic testing (PAUT) has a high precision and efficiency. For the detection of various artificial holes in various magnesium alloys, the resulting gain compensation is positively linearly linked to defect depth. The gain compensation has an inverse relationship with the defect diameter. The magnitude of the fault causes a bigger shift in gain compensation. As a result, when the thickness of a tested material is considerable, various gain values should be chosen to test flaws to avoid an undiscovered defect. While flaws overlap, the accuracy of detection will be hampered by defects adjacent. The direction of the defect influences the test findings as well. It is required to detect flaws in many distinct test surfaces, or to do both longitudinal and transversal wave scanning, in order to correctly locate and differentiate them.

(30) To begin, picture preprocessing techniques such as grayscale transformation, bilateral filtering, and adaptive threshold image segmentation are employed to increase the quality of the casting image. Second, the Relief method is used to pick a key feature subset from the HOG (Histogram of Oriented Gradients), invariant moment, and LBP (Local Binary Pattern) features. Finally, the Adaboost-SVM is employed in the development of the internal crack detection model. Internal crack extraction from an Adaboost-SVM model yields good results. Further detection technology should be encouraged in order to determine interior fracture characteristics such as length, location, and so on.

(31) Internal longitudinal flaws in a novel ultrasonic fatigue testing equipment employing in situ synchrotron tomography demonstrate the machine's ability to induce and track the evolution of an internal micro structurally small fracture in an acceptable testing time. The growth of the fracture causes an increasing homogenous temperature fluctuation in the specimen's centre portion.

(32)When opposed to casting and machining, additive manufacturing (AM) is a revolutionary technique for design and cost of production. Direct energy deposition (DED) technologies are specifically utilised to produce functional metallic components using AM processes. Non-destructive techniques are being studied for online or offline inspection of DED-manufactured components. This work is part of the GeM laboratory's ongoing efforts to create a multi-physics monitoring approach for DED operations. A potential ultrasonic NDT approach for controlling DED-manufactured components is provided in this study. A special focus has been placed on technique calibration in order to achieve the precise size of the identified reflectors. The PAUT sizing predictions were cross-checked with X-ray radiography, allowing the approach to be concluded to identify flaws with sizes ranging from 0.6 mm to 1 mm for aluminium alloy components. The inspection procedure's applicability has been demonstrated in a variety of circumstances, ranging from blocks to industrial and large-scale components. The proposed inspection technique may also be performed on LMD components with the use of a higher frequency probe. Perspectives for using the PAUT technique in situ during DED production have been addressed. The suggested PAUT technique offers potential in situ control of a limited range of components due to the reliable defect sizing step, equipment compact design, processing speed, and ability to perform measurements on a rough surface. However, this study is only a proof of concept, and numerous problems remain.

Ref. no.	Details of article		Critical outcome
1	Material	Aluminium	In rough surface aluminum die casting best suited frequencies of probes ranges between 5 MHz and 10 MHz while surface roughness Ra values varying between 50 µm and 100 µm of castings for the inspection.
	Mfg. Process	high pressure die castings	
	Testing Method	Ultrasonic Testing Immersion PUMA Robot	
2	Material	CFRP	Proposed new ultrasonic methods generating quantitative 3D profiles of porosity in resin layer thickness, ply spacing, and fibre orientation have potential to solve the NDT data analysis for composite aircraft through post-processing of full-waveform data acquired.
	Testing Method	Ultrasonic Testing	
3	Material	1.6 m-long 110 cm-square steel billets	Laser-EMAT (Electro Magnetic Acoustic Transducer) ultrasonics is suitable for on-line at temperatures more than of 700°C surface and internal defect detection in a steel mill. Work claimed novel and continue to EMAT arrays and signal-to-noise ratio.
	Mfg. Process	Steel Rolling	
	Testing Method	Ultrasonic Testing Using Laser EMATs	
4	Material	Ductile Iron	Magnesium content of liquid ductile iron decreased over time from 0.07%Mg immediately after the end of the spheroidization process to 0.04% Mg after approximately 17 min. Total time of pouring the molten metal from the ladles did not exceed 20 min.
	Mfg. Process	Casting	
	Testing Method	ultrasonic testing	
5	Material	CFRP ans sandwitch material	Aerospace equipment made of CFRP inspected by GE sensing & Inspection technique robotic to answer a better solution. Robots are compatible for through transmission testing, pulse echo mode.
	Mfg. Process	Aircraft parts or engine components	
	Testing Method	Ultrasonic testing Robot (Squirting and bubbler syatem)	
6	Material	Alluminum	Al casting samples have been tested

	Mfg. Process	Green sand casting process	for surface and subsurface defects. Surface defects are significantly increased when the pouring rate is increased. However, internal defects are much less severe when the pour rate is decreased.
	Testing Method	1. Visual Inspection 2. Liquid Penetration Test 3. Ultrasonic Testing	
7	Material	Carbon/epoxy and sandwich (Nomex honeycomb core and Kevlar skins) composites	Ultrasonic Testing compared to that of the optical methods is the determination of the depth of the defect and the degree of accuracy obtained. NDT method of Ultrasonic Testing, Infra Red Thermography used to evaluate the efficiency of in-service damages to complex surfaces.
	Mfg. Process	A) Hollow cylindrical rod, ⌀100 mm diameter, 10 mm thick and 1 m long. B) Flat plate, 500 mm X 400 mm X 2 mm C) Angle (around 135) with a slope over the entire length of the specimen (700 mm X 400 mm).	
	Testing Method	IR Thermography Ultrasonic Testing Shearography	
8	Material	Carbon Fibre Composite	Automated ultrasonic testing (UT) has been requested not only for large surface areas, but also for smaller and more complex geometrical components increases testing productivity and eases mechanized testing solutions.
	Testing Method	Industrial robot for Ultrasonic testing	
9	Material	AA5083 Aluminium Alloy	UT technique (according to ASTM specification B548-76) able to identify sub-surface and internal discontinuity in the samples prepared by the third fabrication method. Surface condition and shape of the samples are very important, as smoother surface and less complex shape can generally produce more satisfactory results.
	Mfg. Process	1. conventional casting (melting pouring-solidification) 2. in-situ melting and solidification technique 3. in-situ melting and solidification technique with degassing (injection of argon gas vertical to the surface of the metal) 4. in-situ melting and solidification technique with degassing (injection of argon gas parallel to the surface of the metal)	

	Testing Method	1. Visual Inspection 2. Liquid Penetration Test 3. Ultrasonic Testing	
10	Material	Aluminium alloy 2024 (20 mm× 250 mm× 4 mm)	Stress and residual stress measured by pulse eddy current (PEC) and ultrasonic testing (UT) - both techniques suffer from lack of accuracy. Data fusion is done, which shows effective performance. Useful information obtained is fused using artificial neural network procedure.
	Mfg. Process	Wire cut	
	Testing Method	Pulse eddy current (PEC) Ultrasonic testing (UT)	
11	Material	Cast steel	Investigate cold cracks in the massive steel products using ultrasonic. The low efficiency of the ultrasound input into the metal does not provide the necessary temperature signals in the zone of cracks. Further research is needed to optimize the frequency ranges and the choice of an effective inductor form.
	Testing Method	1. Ultrasonic testing 2. Eddy current infrared thermography	
12	Material	Ti-6Al-4V (Titanium Alloy) 114.3mm X 25.4mm X 25.4mm	Milled surfaces and those parallel to the build direction produce usable data for the detection of flaws at low frequencies. 10 MHz has shown the ability to detect flaws through side surface with low relative error. Future work could expand the frequencies used for inspections or begin to test more complex geometries.
	Mfg. Process	Electron Beam Melting (Additive Manufacturing)	
	Testing Method	Computer Tomography (CT) Scan Ultrasonic Scan	
13	Material	Ni Based Supper Alloy	Resonant ultrasound spectroscopy (RUS) in Ni-based superalloys validated by FEA modelling framework then extended to a turbine blade model for exploring RUS as a NDE technique of grain structure defects in complex geometry components.
	Mfg. Process	Casting	
	Testing Method	Resonant ultrasound spectroscopy	
14	Mfg. Process	Spot Weld	Perfect welds were harder than poor welds. There is a relation between the microhardness of welding and
	Testing	Ultrasonic Testing	

	Method		the ultrasonic attenuation coefficient. The cast microstructure of the weld nugget has coarse grains and high ultrasonic attenuation coefficient.
15	Material	Aluminium castings	Proposed method creates vibration response of the casting shell to be tested by striking a brass tong on the shell at different intensity.
	Testing Method	Performance Frequency Response Method	
16	Material	Al-Si alloys	A new ultrasonic fatigue testing device needs to work on stop criterion to detect smaller cracks, as well as the surface quality of the specimens.
	Testing Method	A new ultrasonic fatigue testing device	
17	Material	ultra-high-strength maraging steel of 18Ni-M250 grade	Ultra-high-strength maraging steel of 250 grade parts of satellite launch vehicles (SLV) checked by multi probe UT for stress-corrosion cracking. Phased Array Ultrasonic Testing (PAUT) better than traditional multi probe and improvising detection by low frequency probes in future.
	Part	Motor case of satellite launch vehicles (SLV)	
	Mfg. Process	Welding od castings	
	Testing Method	Ultrasonic Testing (Conventional) Phased Array Ultrasonic Testing	
18	Mfg. Process	Additive manufacturing	The principle of operation for post-process inspection non-destructive testing (NDT) techniques is presented. Techniques include visual inspection, liquid penetrant testing, magnetic particle testing, eddy current testing, ultrasonic testing, and radiography. The sensitivity, and the advantages and disadvantages of each technique are evaluated.
	Testing Method	visual inspection	
		liquid penetrant testing	
		magnetic particle testing	
		eddy current testing	
		ultrasonic testing	
		radiography	
19	Components	1. Rail wheels 2. Plastic Pipes 3. Spot welding	UT plays an important role for defect detecting in CFRP, GFRP, and BVIDs. Pipes made of high density polyethylene and polyvinyl chloride inspected by UT 10 MHz with a focal distance of 75 mm. It is utilized in rail testing defects smaller than 0.8 mm in size.
	Testing Method	Ultrasonic Testing	

20	Mfg. Process	Casting with defects	In deep learning X-ray by vision and feature based mapping system undetected rate of casting defects detection are lower than 4%, and precision detection of defects is higher than 96%, which can improvise quality of cast product and decrease rejection rate in cast products.
	Testing Method	X-ray & deep convolution neural network (DCNN)	
21	Mfg. Process	Casting	Automatic detection of casting defects. convolutional neural networks (CNN) to locate casting defects in X-ray images show a tradeoff between localization accuracy and inference time. Faster R-CNN models take much longer to generate predictions than the other models.
22	Material	A356 alloy Castings (Gear wheel and Connecting rod)	GBF(granualated blast furnace) slag and sand moulds gives better surface finish and dimensional accuracy. NDE results said sand and slag mould cast product had a sound casting with neither surface, subsurface defects nor internal defects. In sand castings few surface and sub surface defects were noticed in LPT and UT.
	Mfg. Process	Sodium Silicate-CO2 process	
	Testing Method	1. Visual Inspection	
		2. Liquid Penetrant Test	
		3. Ultrasonic inspection	
		4. Radiography	
23	Material	Pure aluminium (99.85%)	Pure Al (99.85%) sand cast with various factors like, pouring temperature, time etc. and their optimization done in Auto-CAST simulation technique. Ultrasonic testing used for detecting subsurface defects and porosity region in specimen. If porosity is present in the casting, then the height of the peaks is very small and they are closer towards each other.
	Mfg. Process	Green sand mould casting	
	Testing Method	1. Liquid Penetration Test 2. Ultrasonic Testing	
24	Material	1m×0.5m x 10mm steel plates	Around 20 MHz reflection should be used for severe, sharp, pitting-type defects. Higher frequencies help to
	Testing	Ultrasonic testing using EMAT	

	Method		lower the feature reflection and improvise detection of mini defects. Combination of two or more methods when inspecting for corrosion at inaccessible locations such as pipe supports recommended.
25	Material	Al 6061	Ultrasonic Flaw Detection for Al6061 cast which is made by stir casting process by pouring of pure Al6061 alloy metal examine the hot forming heat treated specimen properly and all the internal stresses and defects removed.
	Mfg. Process	Stir Casting	
	Testing Method	1. Radiography 2. Magnetic Particle Crack Detection 3. Dye Penetrate Testing 4. Ultrasonic Flaw Detection 5. Eddy Current 6. Electro-Magnetic Testing	
26	Material	Glass Fiber Reinforced Polyester Composites (GFRP) 222mm × 150mm × 3mm with 6 layers	Impact tests at different energy levels were carried out to create three damaged areas in a composite specimen. Results revealed that ultrasonic C-scan is a better method for impact detection in the GFRP materials. This opens up the scope for future work to assess the accuracy of other NDT methods for various materials.
	Mfg. Process	hand lay-up method under the vacuum condition	
	Testing Method	1. Impact Test for defect creation	
		2. Radiography	
		3. Ultrasonic Testing (A-scan & C-scan)	
27	Material	China Fusion Engineering Test Reactor (CFETR) vacuum vessel (VV) welding	Vacuum vessel (VVV) welding is tested by traditional UT and linear probes of phased array ultrasonic testing (PAUT) of austenitic stainless steel. An automatic PAUT system of dual matrix array probe has been recently developed and qualified in ASIPP.
	Mfg. Process	Welding	
	Testing Method	Ultrasonic testing (PAUT)	
28	Material	Alluminum Block	EMAT in pulse echo system has better potential if technique develop for analysis of thickness measurement and crack detection using EMAT.
	Mfg. Process	Machining to create defect of notches	
	Testing Method	Pulse echo using EMAT	

29	Material	AZ80 & AZ31 Magnesium Alloys	Phased array ultrasonic testing (PAUT) has high precision and efficiency in defect detection for casting of magnesium alloys. Different gain values should be selected to test defects to avoid a defect being undetected. Defect orientation also affects the test results as well as the accuracy of detection.
	Mfg. Process	Casting AZ80 casting ingot, AZ31 block semi-continuous casting slab.	
	Testing Method	Phased Array Ultrasonic Testing	
30	Mfg. Process	Casting	Images are preprocessed to improve the casting image quality. Relief algorithm is employed to select key feature subset from HOG (Histogram of Oriented Gradients) and LBP (Local Binary Pattern) feature. Adaboost-SVM is utilized to construct the internal crack detection model.
	Testing Method	Relief algorithm Adaboost-SVM(Support vector machine)	
31	Material	AlSi7Mg0.6 Alluminum Alloy	A new ultrasonic fatigue testing device internal longitudinal defects using in situ synchrotron tomography prove the machine can initiate an internal microstructurally short crack in a reasonable testing time. An increasing homogeneous temperature variation in the specimen central part is observed with the expansion of the crack.
	Mfg. Process	Casting	
	Testing Method	In situ synchrotron ultrasonic fatigue testing	
32	Material	Alluminum Alloy 5356	Aims to develop a multi-physics monitoring methodology to detect defects in aluminium alloy components by means of in situ, non-destructive and non-inertial analysis. Additive manufacturing (AM) methods, direct energy deposition (DED) and advanced metallurgical techniques are used.
	Mfg. Process	Direct energy deposition (Additive manufacturing) Wire Arc Additive manufacturing Laser Metal Deposition	
	Testing Method	phased array ultrasonic testing (PAUT) X-Ray Radiography	

Conclusion and future work

Casting is used to create a wide range of basic and important components. Fewer castings with unacceptable flaws that can be corrected with welding and grinding. To avoid effort in gouging, it is critical to identify the flaw precisely on the inner wall of the casting. In this sense, the ultrasonic method can be highly successful. However, due to the cast construction, only low frequency probes may be utilized. Furthermore, the cast material's reaction to ultrasonic testing is poor. Given these constraints, a viable technique/procedure for fault identification and localization utilizing UT must be devised.

Conflicts of interest

The authors have no conflicts of interest to declare.

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