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INVESTIGATION IN LOCATION OF CASTING DEFECTS USING ULTRASONIC TESTING TECHNIQUE WITH SAFT BASED VALIDATION

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Abstract: In casting components, Non-destructive testing (NDT) techniques are widely used to detect and characterize internal flaws. Among various inspection methods, ultrasonic testing (UT) offers high sensitivity to internal discontinuities and provides a safer alternative to radiographic testing. This research investigates the influence of key parameters such as surface preparation, probe frequency, signal interpretation, and material density on flaw detection accuracy. Advanced UT approaches were employed to generate flaw mapping across different materials, where multi-probe scanning demonstrated improved accuracy, efficiency, and suitability for complex geometries. Synthetic Aperture Focusing Technique (SAFT) images were reconstructed from A-scan ultrasonic data to enhance defect visualization. SAFT enables post-processing beam focusing at each image point, leading to improved spatial resolution and clearer identification of internal defects. The results confirm that optimized UT parameters combined with SAFT imaging significantly improve reliability, defect localization, and overall quality assessment of casting components.

Keywords: Nondestructive testing (NDT), Ultrasonic testing (UT), Casting defects, Synthetic Aperture Focusing Technique (SAFT)

Introduction

Ultrasonic testing (UT) is used for identify and detecting hidden or subsurface defects which are not visible on the surface of metal casting components. The casting components are widely used in industries like aerospace, marine, automobile etc. It is an important and big manufacturing process for making big and complex parts. When it is possible to occur different type of defects in components o parts like cracks, porosity, inclusion, shrinkage cavities, cold shuts etc. These defects can be reducing the structure reliability, fatigue life, mechanical properties of cast parts. For parts safety and maintain product quality, it's important to detect this type of defects in early stage [1-3]. Non-Destructive testing (NDT) is important technique for identify the internal surface integrity of casting process as compare to other NDT methods like magnetic particle testing, radiography, dye penetration testing etc. Ultrasonic testing is one of the most effective techniques for characterization of subsurface defects and identify defects in metallic casting. The main advantage of this techniques is to identify and provide internal discontinuities information even for dense materials. Unlike radiographic inspection, which have radiation hazards and required both side of specimen, it can be work from one side surface and give a real time result. Ultrasonic techniques can be used to evaluate the soundness of weld repaired casting and to observe structural degradation during service life. The integration of UT with three dimensional technologies and computer aided signal interpretation, its open new possibilities for digital defect mapping and automation inspection [4-6].

Working Principle of UT

The Principle of Ultrasonic Testing is based on the propagation of high frequency sound waves through a test material, where reflected signal indicates that the changes in particular area or parts which have presence of defects or changes in material properties. The method works on piezoelectric transducer to emit and receive ultrasonic pulses the travel through the specimen. The working principle of ultrasonic testing (pulse echo method) which is mostly used UT method in testing of metal casing parts and components. In this process, a transducer generates ultrasonic waves that penetrates the specimen's surface. When the waves are touching the boundary like a back wall or any internal defect, a portion of the sound energy reflected back to the transducer and convert into electrical signals. In the image (a), a sound beam traveling through a region where no any type of defect, the ultrasonic pulse reflects only from the back wall, In the result, single echo corresponding to the full thickness of the specimen. The graph shows through the single distinct echo, there is no any type of defect in the specimen. Its represented as "Ep" in the figure. In the image (b), a sound beam traveling through a region and get the defects, ultrasonic pulse reflects from there and did not touch the back wall, leading to multiple reflected signals-one from to the defects till the get back wall.

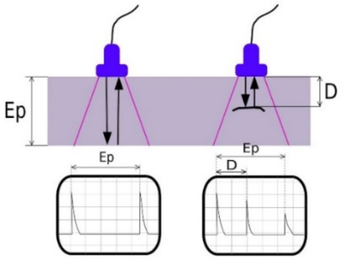

Fig. 1. Working Principle of Ultrasonic testing (pulse-echo method)

The graph shows multiple echo which indicates the defect as a "D" and the go to back wall to complete it. "Ep" represents back wall area, where "D" represents actual internal or subsurface defect in specimen. The distance between these echoes on the time base is proportional to the depth of the defects within specimen [7]. The time-of-flight and amplitude of the received signals, the observer can accurately determine the size and location of internal defects. It is providing precise depth measurement, high sensitivity and the ability to inspect thick sections, making its suitable for welding, casting and structural components. It can be helpful for critical applications such as automotive, aerospace and energy industries. Proper coupling between transducer and specimen surface is necessary to ensure efficient transmission of ultrasonic energy [8].

Literature review

Khalili et al. [9] compares different types of ultrasonic testing methods to find corrosion in internal or inaccessible regions like pipe supports and T joints. Finite element simulations and experimental validations confirm that the integration of A1 & SH1 modes with conventional guide wave techniques give more reliable result for corrosion detection in complex and inaccessible structural regions. Huaishu et al. [10] established the UT which provides a reliable and non-destructive approach for find and evaluate the depth of induction hardened layers in metallic materials. By using Short Time Fourier Transform (STFT) and Fast Fourier Transform (FFT) to analyze ultrasonic signals, it shows a clear correlation between hardened layer thickness and variations in ultrasonic amplitude and frequency response. As the hardened layer depth increases, the reflected signal amplitude rises. Ultrasonic testing gives faster, repeatable and non-destructive evaluation as compare to traditional metallographic or hardness-based methods. Brugger et al. [11] introduces an innovative ultrasonic fatigue testing device which are capable to generating biaxial proportional stress states under gigacycle loading conditions. They demonstrate that the device ensures stable resonance and reproducible loading, enabling efficient evaluation of fatigue life beyond 10^9 cycles. It is advance ultrasonic fatigue testing for multiaxial evaluation of materials in the very high cycle fatigue (VHCF) domain. Wilczek et al. [12] compared ultrasonic, eddy current, pulsed infrared thermography and radiography techniques for evaluating porosity in aluminum pressure die casting. They observed integrating radiographic imaging with digital image analysis offers a reliable an efficient approach for non-destructive porosity evaluation in aluminum castings. For detecting and quantifying internal porosity without requiring surface preparation, radiographic testing combined with computer-based image segmentation proved the most effective in aluminum casting. Moghanizadeh et al. [13] observe ultrasonic testing serves as an efficient non-destructive approach for evaluate the microstructural characteristics and physical integrity of resistance spot welds. Experimental observations further show, perfect welds exhibit higher microhardness values than defective ones validating the use of ultrasonic attenuation as a diagnostic indicator. Chen D et al. [14] works on the application of scanning pulsed eddy current (PEC) as an effective NDT for evaluate low energy impact damage in carbon fiber reinforced polymer (CFRP) laminates and internal defects in honeycomb sandwich structures. Magnetic field intensity and conductivity variation are used to characterize structural degradation. Experiments finds PEC effectively identified concave deformation caused by impact energies ranging from 4 J to 12 J in CFRP specimen. Despite more time intensive, PEC provided deeper material penetration and a clearer representation of subsurface damages. Schwabe et al. [15] introduce a novel robotic based approach for UT of composite structures, particularly carbon fiber reinforced polymer (CFRP) parts used in aerospace applications. It compares various coupling method that robot assisted squirter and bubbler systems deliver high quality coupling and adaptability to complex geometries. Through transmission and pulse echo configuration using phase array probes enhance detection accuracy and productivity, especially in large and curved components. Sharma et al. [16] enlighten the critical role of UT as a non-destructive evaluation tool across diverse mechanical engineering applications. UT has highly effective in characterizing and detecting flaws in polymer components, welds, rails, metals, composites etc. Its ability to detect and observe micro level discontinuities such as cracks, delamination and barely visible impact damages in materials. The techniques adaptability to pulse-echo and through-transmission modes allows real time and in situ defect evaluation. Ultrasonic Testing sketch and detection results shows in figure 2 for understanding the results. The advancement such as laser ultrasonic testing and automated inspection systems have extended UT's utility in complex geometry.

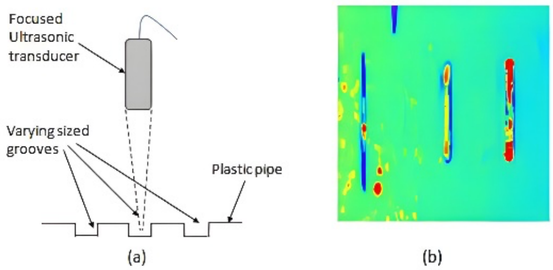

Fig. 2. (a) Ultrasonic testing sketch (b) Detection result [16]

Bejaxhin et al. [17] observed the effective integration of NDT and microstructural analysis to evaluate casting quality and mechanical performance of A16060 alloy. Hardness testing revealed a significant increase in Brinell & Rockwell values for multi heat treated samples compared to mono treated ones, attributed to enhanced grain boundary refinement. Radiographic inspection confirmed that optimized heat treatment and hot pressing at 450-600 C eliminated internal casting defects like inclusions and voids. Dimensional stability under compressive loading is improved which is observed by finite element simulation. Murthi et al. [18] observed ultrasonic and radiographic results, its confirmed that the minimal surface discontinuities as compared to sand mould casting while liquid penetrant in the absences of subsurface and internal flaws. Through comprehensive non-destructive evaluation like, liquid penetrate testing, radiography, visual inspecting, ultrasonic testing; the A356 alloy casting produced using GBF slag exhibited good surface finish, defect free structure and dimensional accuracy. Its shows that GBF slag moulds exceed the quality of traditional sand moulds in a sustainable and cost-effective substitute. Patil et al. [19] introduces cost-effective, innovative and reliable non-destructive testing method which is Performance Frequency Response Method (PFRM). It's used vibration parameters like frequency, acceleration, displacement etc. and generated through mechanical impact. The method successfully distinguishes between defective casting and sound. Result concludes the defect free aluminium casting exhibit displacement, acceleration, frequency ranges of 37-48 mil, 640-660 mm/s^2, 11-14.7 Hz respectively, when defective castings show lower values significantly. As compared with conventional methods, PFRM have a simpler setup, lower operational cost and faster testing. It makes comparative good for real time industrial quality control. Ferguson et al. [20] presents a Conventional Neural Networks (CNNs) technique for automatic localization of defects in metal casting. The study utilizes transfer learning to train these models on relatively small datasets. Results shows, CNN Based approaches can detect casting defects accurately and efficiently. Mozammil et al. [21] investigates the effect of gating system design, pouring time and pouring temperature on porosity formation in aluminium casting using experimental and simulation-based approaches. NDT methods like dye penetrant inspection and ultrasonic for detect internal and surface porosities respectively validating simulation results. Results shows that optimized gating design effectively minimizes shrinkage induced porosity and increasing pouring temperature elevated gas entrapment. Idris et al. [22] demonstrates the significance of integrating multiple non-destructive testing (NDT) methods for accurate quality assessment of aluminum alloy castings, specifically AA5083. non-destructive testing (NDT) techniques like UT, VT, Liquid Penetrant Testing (LPT). It confirmed that NDT reliability is strongly influenced by calibration, operator skill and surface smoothness. Jin et al. [23] presents advance research frameworks for finding accurate identification of internal cracks in casting. It is integrating the relief feature selection algorithm with the Adaboost SVM classifier. By using image preprocessing techniques like, bilateral filtering, grayscale transformation, and adaptive threshold segmentation with hybrid feature extractions like HOG, invariant moment feature, LBP; its increase classification precision and defect visibility effectively. The relief algorithm optimizes the feature subset by selecting the improving computational efficiency, most sensitive attributes, and reducing redundancy. Experimental Validation done by industrial X-ray datasets, it is confirmed that proposed model has a good stability, superior accuracy and generalization performance compared to bagging-KNN classifiers and SVM. The ensemble approach improved defect localization reliability and reduce false negatives. Jadayil et al. [24] systematically using the non-destructive testing (NDT) to research the influence of molten metal pouring rate on subsurface defects and formation of surface in aluminium casting. By using of Penetrant Testing (PT) and Ultrasonic testing (UT) examined ten green sand cast aluminium sample to evaluate surface and internal defect characteristics. Experimental observations find a direct relationship between attributed to turbulence and gas entrapment, increased pouring rate and surface defect formation. Subsurface defects decreased when pouring rates were high as the pressurised molten metal expelled entrapped gases and inclusions towards the surface. Penetrant Testing (PT) give effective surface defect visualization and Ultrasonic testing (UT) accurately characterizing internal discontinuities without damaging the samples. Tupaj et al. [25] established a quantitive relationship between microstructural parameters and wave velocity of ductile iron casting, specifically the graphite shape index and the number of graphite precipitations. In this, research concludes that a reduction of magnesium from 0.07% to 0.04% significantly decreased ultrasonic velocity and graphite spheroidization testing. The using of UT as a reliable, no destructive tool to evaluate the degree of nodularity and structural uniformity in ductile iron. Honaver et al. [26] reviewed an ultrasonic testing as a vital non-destructive method for detecting internal flows in metals. It describes how factors like transducer type, frequency and material structure influence the accuracy and sensitivity of inspection. The limitations of UT like grain noise and signal attenuation affect performance in coarse-grained materials where phased array, guided wave techniques, laser ultrasonic etc. have significantly enhanced detection capability and automation. They conclude, UT remains one of the most adaptable and effective tools for evaluating metallic components with modern developments in digital processing and artificial intelligence for improving reliability and industrial applications. Parraet al. [27] introduces a novel orthogonal co located coil (OCLC) EMAT to perform thickness measurement and crack detection in a single setup which is capable of generating two perpendicular linearly polarised shear waves. In experimental validation and 3D finite element simulation, it shows the differences in reflected wave amplitude between the two polarisations can accurately indicate the presence and orientation of surface breaking cracks. As compare to traditional UT, the dual function technique more suitable for industrial applications involving metallic components. Arhamnamazi et al. [28] compares the effectiveness of C-scan & X-ray radiography to find low velocity impact damage in GFRP composites materials. Using MSE & PSNR, an image quality assessment parameter; its shows that as compared to X ray radiography, the ultrasonic C-scan method have higher precision and clearer defect boundaries. C scan testing accurately detected delamination and internal impact zones while X-ray images suffering from low contrast and scattering due to high absorption of glass fibres. Xue et al. [29] observed the effect of microstructure and defect parameters on gain compensation during phased array ultrasonic testing (PAUT) of AZ80 and AZ31 magnesium alloy. The results shows that gain compensation decreases with larger defect diameters and proximity to boundaries and increases linearly with defect depth and grain size. Defect overlap and orientation affected emphasizing the need for multi surface or dual wave scanning, signal accuracy for precise evaluation. The gain compensation as a reliable quantitative parameter for defect characterisation in Magnesium alloys and provide valuable guidance for optimizing PAUT in industrial casting inspection. Cheprasov et al. [30] inspect the combined use of eddy-current infrared thermography and ultrasonic for detecting cold cracks in cast steel components. The ultrasonic thermography method based on localized heating caused by internal friction at crack surfaces producing clear thermal signatures of both surface and subsurface defects. Eddy current thermography utilizes electromagnetic induction to produce joule heating around cracks to making it highly sensitive to surface discontinuities. The observation for this, integration of this methods improves defect detection reliability and offers promising non-destructive approach of structural integrity assessment in steel casting process. Garnier et al. [31] conducted a comparative study on Shearography, Infrared Thermography (IRT), and Ultrasonic Testing (UT) for detects defects in aeronautical composite structures. The main concentration of work to identify defects like disbonding, delamination and impact damages on various geometrically complex composite specimen. They conclude that, UT take a more time for inspection and it's had a complex setup for non-flat surfaces but it is the more accurate in observe and find the defect depth and size in the object. Infrared thermography has a good defect dimension identifying ability and provide quick detection of defect while Shearography has clear visualisation of surface and sub surface defects with less setup time. It is effective and efficient for complex geometries. Amenabar et al. [32] do a comparison of four most usable non-destructive testing process in industries like; Ultrasonic testing, Shearography, Thermography and X ray computed tomography (CT) for find a defect in thick composite wind turbine blades. They concluded; CT used as a reference for detailed analysis of defects. Thermography and Ultrasonic Testing identified most practical method for big size composites specimen inspection like turbine blades etc. Messager A et al. [33] works for in situ observation of internal fatigue crack initiation and growth in cast aluminium alloys. They used novel ultrasonic fatigue testing system integrated with synchrotron X ray tomography. The setup enables testing at 20 kHz, allowing real time detection of defect through FFT based model analysis and monitoring of damage evolution using infrared thermography. It shows clear internal microstructurally short crack visualisation and their correlation with thermal and nonlinear acoustic responses. This process reduces testing time and generate precise 3D insights into crack behaviour at very high cycle fatigue regimes. Kumar A. et al [34] presents a novel in situ approach for identify fatigue damage in cast Al-Si-Cu-Mg alloys using nonlinear ultrasonic measurements. They conclude, higher stress amplitudes and larger pores significantly reduces the initiation phase of fatigue life, its proved that internal defects have a major role in damage evolution. This method is effective for real time monitoring of fatigue progression, it is powerful non-destructive testing for assessing structural integrity in cast alloys.

Methodology

The main aim of this research is to identify and develop an efficient, systematic and accurate methodology for the find and localization of sub surface and internal defects in casting components using ultrasonic testing. This objective can be achieved, if we focused on specific area which are mentioned below:

To identify the limitations of various conventional ultrasonic inspection techniques which are used for detecting the defects in casting components where high signal scattered reduces defect visibility. To observe and analyse the ultrasonic testing data taken by A-scan and find suitable characterizing for different types of casting defects. To develop and validate a defect detection methodology which can be decision making in industrial casting inspection and reduces the risk of components failure during operations. The detailed explanation of the SAFT Ultrasonic Analysis Framework shown in figure 4, a physics-based and fully interpretable ultrasonic signal processing methodology for defect characterization using the Synthetic Aperture Focusing Technique (SAFT). The workflow illustrated in the flowchart, consists of sequential and logically connected stages, each grounded in ultrasonic wave propagation principles.

1. Ultrasonic testing data acquisition and preprocessing
2. Physics-based feature extraction
3. Feature selection based on model interpretation strategy
4. SAFT reconstruction (model-based processing)
5. Image normalization and dB scaling
6. Defect localization and sizing

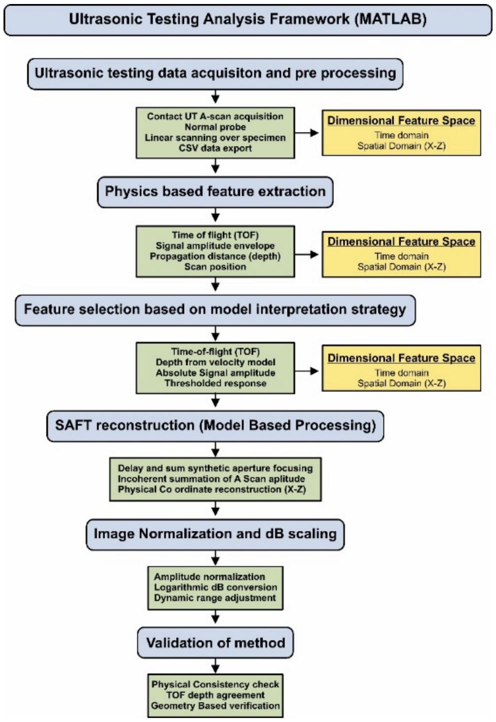

Fig. 4. SAFT Ultrasonic Analysis Framework

Specimen preparation and experimental setup

A two-dimensional schematic representation of the specimen geometry and the location of the artificially introduced defects is shown in Figure 5. The figure illustrates the overall dimensions of the square specimen 100 × 100 × 18 mm along with the type, size, and position of predefined defect. The schematic provides a clear visual reference for correlating defect locations with experimental observations obtained during inspection and testing. The inclusion of controlled artificial defects ensures repeatability and reliability in defect detection studies and allows systematic validation of the employed inspection methodology. 100 X 100 X 18 mm square specimen was prepared by the green sand-casting method with a required all necessary allowances and tolerances. The mould was prepared by mixing clay, sand and water in the ratio of 2:7:1 respectively. The fitness of sand maintained within the range of 2.4-3.0, which is considered best according to the AFS standards. The clay and sand were mixed in a sand muller machine with the water as per requirement to mix properly for specimen preparation. After proper mixing the green sand was removed from muller and placed into the cope and drag mould box to produce the mould cavity. The positive and negative ends of two thermocouples wires were welded together to form a junction for temperature measurement. The thermocouple tip was inspected carefully for temperature measurement. The moulten metal poured into the mould at a pouring temperature of 740º C. The process parameters were used during casting operation is shown in table 1.

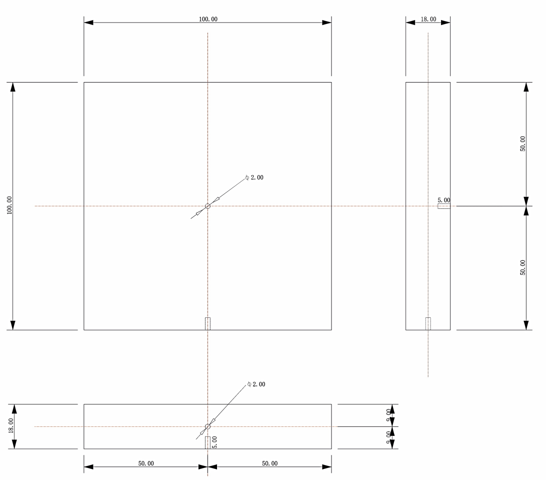

Fig. 5. 2D schematic representation of the specimen geometry and the location of the artificially introduced defects

For measuring temperature of process, chromel-alumel thermocouple wires inserted into a ceramic insulator tube. As shown in figure 6, pouring molten metal to green sand mould to finished specimen for testing.

Table 1: Process parameters for casting operation

Parameter designation	Process Parameter	Rate
A	Pouring temperatur (^0C)	740
B	Pouring time (min)	20
C	Sand mixing tim (min)	4

D	Pouring height (cm)	15
E	Cooling time (min)	60

After the completion of solidification of metal, it will be removed from the mould. The specimen was machined on a milling machine to achieve the final dimension 100 X 100 X 18 mm. According to standard testing procedure, the surface of the specimen facing the probe should be perpendicular to the direction of ultrasonic energy flow and machined obtain an improved surface finish for accurate measurement and analysis. After the process, digital vernier calliper is used to measure a dimension of specimen for accurate result. The process was carried out prior to machining and testing to confirm dimensional accuracy as per required specifications. The measurement of specimen helps in maintaining consistency for all samples. It is ensuring reliable comparison between the specimen results. The inspection also verifies alignment and proper surface finish after casting and preliminary machining operations. The chemical composition of specimen alloy examined as per below table data.

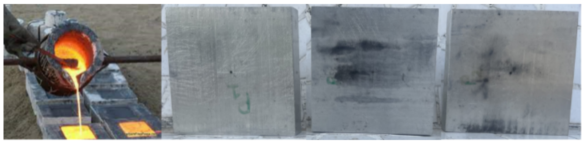

Fig. 6. Casting and specimen preparation process

Table 2: Chemical composition of aluminium alloy

Comp %	**(Cu)**	**(Mg)**	**(Si)**	**(Fe)**	**(Al)**
	2.6 -3.6	0.05	4.5 - 6	0.6	other
	(Mn)	**(Ni)**	**(Zn)**	**(Ti)**	**-**
	0.55	0.1	0.2	0.25	-

Experimental Procedure

This specimen examined using contact type perpendicular transducer of standard dimensions. It is operating across different frequency from 0.5 MHz to 4 MHz. Up to 1 MHz frequencies is preferred for operating system because it provide better penetration, reduced scattering in materials and lower attenuation with rough surface also. The Low frequency probes give a larger beam divergence angle as a result, due to this its limited to detect very small or fine defects in specimen. To identify and resolve this limitation, a modified inspection approach will be proposed to enhance the detection accuracy of smaller defects without any compromising penetration depth. As shown in figure 7, schematic representation of ultrasonic wave propagation through the workpiece, illustrating the initial pulse, defect echo, and back wall echo on the CRT display. The reflected signals indicate the presence and location of internal defect based on time delay and amplitude. The dimension of probe was selected based on standard foundry design principles to ensure smooth metal flow, minimize turbulence and achieve uniform solidification.

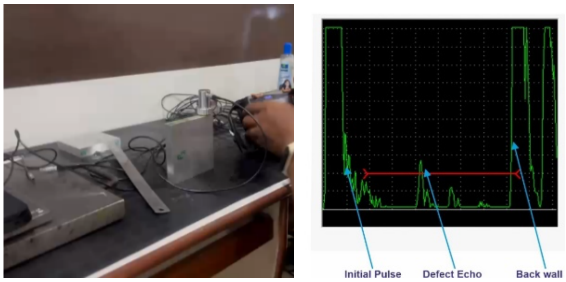

Fig. 7. Ultrasonic testing (UT) process and result display

Geometry of sprue, pattern and runner, ingate has been taken as shown in table 3. The parameters for identify defect in specimen were carefully selected to achieve optimal casting quality. The mould temperature and pouring temperature were controlled to ensure proper fluidity and solidification of the molten metal. The crucible volume capacity ensured a consistent supply of molten metal for uniform casting across multiple specimens. Pouring time for moulten metal was maintained to avoid turbulence during filling, while degassing was performed to minimize gas porosity.

Table 3: Geometry for sprue, pattern, runner and ingate,

Geometry	Size (mm)			Diameter (mm)	
	Length	Height	Width	Top	Bottom
Sprue	-	190	-	15	13
Ingate	60	15	10	-	-
Pattern/ Plate	140 & 130	20 & 18	140 & 130	-	-
Runner	245	-	-	-	-

Result and discussion

The Ultrasonic Testing A-scan has been done to investigate the sample to observe defects in specimen. Test specimen tested by a contact type perpendicular transducer with standard dimensions at various frequency range of 4 MHz normal probe with 20 db drop method. The simplified Ultrasonic Testing Signal Interpretation as shown in figure 8. Length of 100 mm divided into equal sections by a grid. At each end of the specimen, there are two circular overlapping path is given for scanning of the probe with a diameter of 10 mm, likely representing defect locations.

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ZERO	GATEa	GATEb	MEMORY	DAC
3.29	PLOGIC	OFF	A-SCAN	OFF
RANGE	STARTa	STARTb	MEM NO	STARTa
120	23.7 mm	40.0 mm	237	23.7 mm
MTL VEL	WIDTHa	WIDTHb	ACTION	DAC dB
6300	77.8 mm	50.0 mm	SAVE	0.0 dB
DELAY	LEVELa	LEVELb	NOTE	TL
0.00	20 %	40 %	ENTER	0.0 dB
GAIN	SP1:50.02	DP1:50.02	SD1:0	Amp1:127%
48.0 dB	SP2:50.02	DP2:50.02	SD2:0	Amp2:26%

Fig. 8. Ultrasonic Testing A-scan data

A Ø10 mm normal ultrasonic probe is used to perform an A-scan inspection, with the arrows in the diagram indicating the direction of ultrasonic testing from the probe into the sample. The purpose of this setup is to evaluate the sample's response to ultrasonic testing when it contains determined defects, helping in calibration, validation, and understanding of defect detection characteristics in ultrasonic non-destructive testing (NDT). The simplified Ultrasonic Testing Signal Interpretation with the reference of above image is: The horizontal axis represents time or converted distance, moving left to right as time-of-flight increases. Many systems convert this to depth (mm) using material velocity. The vertical axis shows echo amplitude (signal strength) tall spikes indicate strong reflections, while smaller signals represent weaker echoes. The initial large spike near the left edge corresponds to the front-surface echo or probe ringdown, followed by a dead zone where near-surface defects may not be detected. The backwall echo, appearing farther right, represents reflection from the rear surface of an intact part. Intermediate echoes between these indicate possible defects (voids, cracks, inclusions, etc.), where their horizontal position gives depth and height shows reflection strength. A red horizontal line marks the detection threshold, and red brackets or arrows define the gate region monitored for signals.

SAFT Image generation through MATLAB:

After the process of A scan UT as described above, the complete set of A-scan data obtained from the entire scanned region was used to generate an image through MATLAB. For each probe position along the predefined grid and circular scanning paths, the time-domain ultrasonic signals were recorded and stored digitally. These signals contain amplitude and time-of-flight information corresponding to reflections from the front surface, internal features, and the backwall of the specimen. All data of A-scan converted in table form for the import in MATLAB for post-processing and visualization. In MATLAB, signal conditioning steps such as time gating, normalization, and noise suppression were used to ensure consistency across all scan positions. The gated signals corresponding to the region of interest within the specimen thickness were extracted and their amplitudes were mapped spatially according to the probe location during scanning. By assembling the processed A-scan signals from successive scan points, a two-dimensional SAFT (Synthetic Aperture Focusing Technique) image was generated.

Mathematical Steps for Converting A-Scan Data into SAFT Image Using MATLAB

1. Representation of A-Scan Signal: Each ultrasonic A-scan signal can be represented mathematically as: $A(t)=a(t)$

Where, $A(t)$ = ultrasonic signal amplitude,

t = time of flight

Each signal contains reflections from:

Front surface | Internal defects | Back wall

2. Time-to-Depth Conversion: To convert time-of-flight into physical depth, the following relation is used:

$d = \frac{V \times T}{2}$

where, d = depth of reflector (mm)

v = ultrasonic wave velocity in material (m/s)

t = time of flight

Division by 2 accounts for round-trip travel of the ultrasonic wave. This conversion allows mapping of A-scan signals along the specimen thickness.

3. Formation of A-Scan Data Matrix: The A-scan signals collected at different probe positions are arranged into a matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M1} & a_{M2} & \cdots & a_{MN} \end{bmatrix}$$

where, Rows represent depth (or time) samples

Columns represent probe scan positions

This matrix is imported into MATLAB from the Excel file

4. Signal Normalization: To ensure uniform comparison across all A-scans, normalization is applied:

$$A_{norm}\,(i, j) = \frac{A\,(i,j)}{\max\,(|A|)}$$

This step scales amplitudes between 0 and 1, improving image contrast.

5. Time Gating (Region of Interest Selection): A depth gate is applied to focus only on the defect region:

$$\text{Agated}\,(d) = \begin{cases} A(d), & d1 \le d \le d2 \\ 0, & otherwise \end{cases}$$

This removes unwanted signals such as front surface and backwall echoes.

6. Synthetic Focusing (SAFT Principle): In SAFT, signals from multiple scan positions are time-shifted and summed:

$$S\,(x, z) = \sum_{i=1}^{N} Ai\,(t - \Delta ti\,(x, z))$$

Where, S (x, z) = focused signal at image point, Δ ti = time delay correction, x = scan position, z = depth

This synthetic focusing improves spatial resolution and defect clarity.

7. Image Intensity Mapping: The focused amplitude values are mapped to image intensity:

$I\,(x, z) = |S\,(x, z)|^2$, Higher intensity indicates stronger reflections (possible defects).

The SAFT image shows a spatial distribution of ultrasonic response within the object or specimen where variations in signal amplitude and intensity correspond to material defects or discontinuities. Regions with higher reflected energy appear as brighter or higher-intensity zones, indicating potential defect locations, while uniform areas with lower intensity suggest sound material. This transformation from one-dimensional A-scan signals to a two-dimensional SAFT image enhances defect visualization, allows for better correlation between known defect locations and ultrasonic response and improves interpretability. The use of MATLAB for SAFT image generation thus provides an effective tool for validating defect detection capability, improving calibration accuracy, and supporting quantitative analysis in ultrasonic non-destructive testing of the specimen.

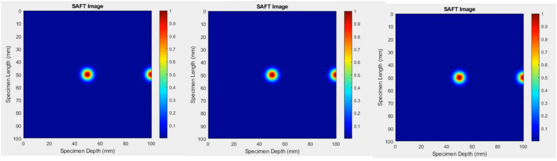

Fig. 9. SAFT Image generated by MATLAB

The generated SAFT image as shown in figure 9, from the complete A-scan ultrasonic data which are getting by inspection on UT. The image maps the ultrasonic response in terms of specimen length which shows on vertical axis and specimen depth shows on horizontal axis. The blue area indicating uniform material with no internal reflections of any type of defect which confirms the absence of defects in these regions. Two high-intensity regions are clearly visible in the image, represented by color bands of green, yellow, and red. These indicate the strong ultrasonic reflections due to internal defects and discontinuities in the specimen. The highest reflection intensity is indicated in red color, gradually decreasing to yellow and green. It is representing the spread of reflected ultrasonic energy around the defect location. The defects are highlighted using dashed circular boundaries. From the highlighted regions, the approximate defect size is observed as red region, which closely matches the predefined defect made during specimen preparation. The slight spread beyond the actual defect boundary can be attributed to beam divergence of the ultrasonic wave and signal processing effects during SAFT image reconstruction. The locations of the defects along the specimen length and depth are consistent with the planned scanning paths and known defect positions. This confirms the accuracy of the A-scan data acquisition and the effectiveness of the MATLAB-based SAFT image generation process. Compared to conventional single A-scan interpretation, the SAFT image provides a clearer and more natural visualization of defect location, size, and relative intensity.

Conclusion

In this study, ultrasonic testing of the test specimen was successfully carried out by a contact type perpendicular transducer with standard dimensions at various frequency range of 4 MHz normal probe with 20 db drop method. The simplified Ultrasonic Testing Signal Interpretation scan the test specimen of 100 X 100 X 18 mm. Circular overlapping scanning paths were followed at predetermined locations using a Ø10 mm probe, representing known defect positions. This Ultrasonic testing experimental setup enabled reliable calibration, interpretation of ultrasonic responses and validation from internal defects. The A-scan signals obtained from probe position provided detailed time of flight and amplitude information related to the internal reflectors, front surface, and backwall of the specimen. These signals were interpreted using standard ultrasonic signal analysis principles, where intermediate echoes between the front surface and backwall reflections indicated the presence of internal discontinuities. However, interpretation of individual A-scans alone can be complex and operator-dependent, especially when multiple scan positions are involved. To solve these limitations and make it easy to understand and identify the defect, the complete A-scan data was processed in MATLAB to generate an SAFT (Synthetic Aperture Focusing Technique) image. Signal conditioning steps such as noise suppression, gating, and normalization were applied to maintain consistency across the data. The reconstructed SAFT image provided a two-dimensional visualization of the ultrasonic response in terms of specimen depth and length, significantly improving defect visibility and spatial understanding. The SAFT image clearly shows two high intensity regions corresponding to the internal defects which are predefined. The defect size shows in the image closely match the actual defect dimensions. The minor spreading of the reflected energy around the defect regions indicates the attribute of ultrasonic beam divergence and reconstruction effects inherent to the imaging process. The accurate localization and sizing of defects confirm the effectiveness of the scanning strategy, chosen probe frequency, and signal processing approach.

The results demonstrate that combining conventional A-scan ultrasonic testing with MATLAB-based SAFT image reconstruction enhances defect detection, interpretation capabilities, and sizing. The approach provides a reliable and strongest method for avoid difficulties that can occur when interpreting individual A-scan signals, visualizing internal defects, supports calibration and validation of ultrasonic testing parameters. This methodology is effective and practical tool for non-destructive testing of plate-type specimens and can be extended to more complex geometries and materials in future studies.

References

[1] L. W. Schmerr, *Fundamentals of Ultrasonic Nondestructive Evaluation: A Modeling Approach*, 2nd ed. New York, NY, USA: Springer, 2016.

[2] P. P. Bhatnagar and V. Kumar, “Comparison of ultrasonic and radiographic techniques for casting inspection,” *Journal of Materials Processing Technology*, vol. 214, no. 10, pp. 2110–2116, 2014.

[3] D. K. Hsu and D. O. Thompson, “Recent advances in ultrasonic NDE for defect detection,” *Materials Evaluation*, vol. 75, no. 5, pp. 607–616, 2017.

[4] A. Nageswara Rao and B. V. S. Reddy, “Evaluation of internal defects in aluminum alloy castings using ultrasonic testing,” *International Journal of Advanced Manufacturing Technology*, vol. 96, no. 9, pp. 3729–3738, 2018.

[5] S. A. M. Tabrizi and M. A. Rezaee, “3D ultrasonic imaging and defect characterization in steel castings,” *NDT & E International*, vol. 102, pp. 109–117, 2019.

[6] M. D. Moles and R. C. Addison, “The effect of grain size on ultrasonic attenuation and defect detectability in cast materials,” *Ultrasonics*, vol. 44, no. 1, pp. 77–84, 2006.

[7] ASTM E114-22, *Standard Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method*, ASTM International, West Conshohocken, PA, USA, 2022.

[8] C. Hellier, Handbook of Nondestructive Evaluation, 2nd ed. New York, NY, USA: McGraw-Hill, 2012.

[9] Khalili, P., & Cawley, P. (2018). The choice of ultrasonic inspection method for the detection of corrosion at inaccessible locations. NDT & E International, 99, 80-92.

[10] Huaishu, H. O. U., Dong, Y. X., Ding, L. U., Xinchong, F., & Jicai, S. (2021, July). Detection and Analysis of Metal Induction Hardened Layer Based on Ultrasonic Technology. In Journal of Physics: Conference Series (Vol. 1965, No. 1, p. 012146). IOP Publishing.

[11] Brugger, C., Palin-Luc, T., Osmond, P., & Blanc, M. (2017). A new ultrasonic fatigue testing device for biaxial bending in the gigacycle regime. International Journal of Fatigue, 100, 619-626.

[12] Wilczek, A., Długosz, P., & Hebda, M. (2015). Porosity characterization of aluminium castings by using particular non-destructive techniques. Journal of Nondestructive Evaluation, 34(3), 26.

[13] Moghanizadeh, A. (2016). Evaluation of the physical properties of spot welding using ultrasonic testing. The International Journal of Advanced Manufacturing Technology, 85(1), 535-545.

[14] He, Y., Tian, G., Pan, M., & Chen, D. (2014). Non-destructive testing of low-energy impact in CFRP laminates and interior defects in honeycomb sandwich using scanning pulsed eddy current. Composites Part B: Engineering, 59, 196-203.

[15] Schwabe, M., Maurer, A., & Koch, R. (2010, November). Ultrasonic testing machines with robot mechanics–a new approach to CFRP component testing. In 2nd International Symposium on NDT in Aerospace, Germany (pp. 1-5).

[16] Sharma, A., & Sinha, A. K. (2018). Ultrasonic testing for mechanical engineering domain: present and future perspective. International journal of research in industrial engineering, 7(2), 243-253.

[17] Bejaxhin, A. B. H., Paulraj, G., & Prabhakar, M. (2019). Inspection of casting defects and grain boundary strengthening on stressed Al6061 specimen by NDT method and SEM micrographs. Journal of Materials Research and Technology, 8(3), 2674-2684.

[18] Murthy, I. N., & Rao, J. B. (2018). Non destructive evaluation of A356 alloy castings made in sand and granulated blast furnace slag moulds. Materials Today: Proceedings, 5(1), 168-174.

[19] Patil, S. A., & Darade, P. D. (2017). Application and Performance Frequency Response Method as NDT Tool to Detect Defects in Castings. Materials Today: Proceedings, 4(8), 8463-8468.

[20] Ferguson, M., Ak, R., Lee, Y. T. T., & Law, K. H. (2017, December). Automatic localization of casting defects with convolutional neural networks. In 2017 IEEE international conference on big data (big data) (pp. 1726-1735). IEEE.

[21] Mozammil, S., Karloopia, J., & Jha, P. K. (2018). Investigation of porosity in Al casting. Materials Today: Proceedings, 5(9), 17270-17276.

[22] Idris, J., & Al-Bakoosh, A. (2014). Application of non-destructive testing techniques for the assessment of casting of AA5083 alloy. Journal of Advanced Research in Applied Mechanics, 3(1), 25-34.

[23] Jin, C., Kong, X., Chang, J., Cheng, H., & Liu, X. (2020). Internal crack detection of castings: a study based on relief algorithm and Adaboost-SVM. The International Journal of Advanced Manufacturing Technology, 108(9), 3313-3322.

[24] Jadayil, W. M. A. (2011). Studying the effects of varying the pouring rate on the casting defects using nondestructive testing techniques. JJMIE, 5(6), 521-526.

[25] Orłowicz, W., Tupaj, M., Mróz, M., & Guzik, E. (2010). Evaluation of ductile iron casting material quality using ultrasonic testing. Journal of Materials Processing Technology, 210(11), 1493-1500.

[26] Honarvar, F., & Varvani-Farahani, A. (2020). A review of ultrasonic testing applications in additive manufacturing: Defect evaluation, material characterization, and process control. Ultrasonics, 108, 106227.

[27] Parra-Raad, J., Khalili, P., & Cegla, F. (2020). Shear waves with orthogonal polarisations for thickness measurement and crack detection using EMATs. NDT & E International, 111, 102212.

[28] Arhamnamazi, S. A., Bani Mostafa Arab, N., Refahi Oskouei, A., & Aymerich, F. (2019). Accuracy assessment of ultrasonic C-scan and X-ray radiography methods for impact damage detection in glass fiber reinforced polyester composites. Journal of Applied and Computational

Mechanics, 5(2), 258-268.
[29] Xue, S. N., Le, Q. C., Jia, Y. H., Jiang, L. P., Zhang, Z. Q., & Bao, L. (2019). Ultrasonic flaw detection of discontinuous defects in magnesium alloy materials. China Foundry, 16(4), 256-261.
[30] Cheprasov, A. I., Knyazev, S. V., Usoltsev, A. A., Dolgopolov, A. E., & Mamedov, R. O. (2016, September). Detection of cold cracks in the cast-steels by the methods of ultrasonic and eddy-current infrared thermography. In IOP Conference Series: Materials Science and Engineering (Vol. 150, No. 1, p. 012026). IOP Publishing.
[31] Garnier, C., Pastor, M. L., Eyma, F., & Lorrain, B. (2011). The detection of aeronautical defects in situ on composite structures using Non Destructive Testing. Composite structures, 93(5), 1328-1336.
[32] Amenabar, I., Mendikute, A., López-Arraiza, A., Lizaranzu, M., & Aurrekoetxea, J. (2011). Comparison and analysis of non-destructive testing techniques suitable for delamination inspection in wind turbine blades. Composites Part B: Engineering, 42(5), 1298-1305.
[33] Messager, A., Junet, A., Palin-Luc, T., Buffiere, J. Y., Saintier, N., Ranc, N., ... & Nadot, Y. (2020). In situ synchrotron ultrasonic fatigue testing device for 3D characterisation of internal crack initiation and growth. Fatigue & Fracture of Engineering Materials & Structures, 43(3), 558-567.
[34] Kumar, A., Torbet, C. J., Pollock, T. M., & Jones, J. W. (2010). In situ characterization of fatigue damage evolution in a cast Al alloy via nonlinear ultrasonic measurements. Acta Materialia, 58(6), 2143-2154.