DEPARTMENT OF PHYSICS

ST. TERESA'S COLLEGE (AUTONOMOUS), ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled "**DIGITAL HOLOGRAPHY: A NON-DESTRUCTIVE TECHNIQUE FOR DETERMINATION OF THERMAL EXPANSION COEFFICIENT**" is an authentic work done by **SREYA P (AM22PHY013)** under my guidance at Department of Physics, St. Teresa's College (Autonomous), Ernakulam for the partial fulfillment of the requirements for the award of the Degree of Master of Science in Physics during the year 2023-24. The work presented in this dissertation has not been submitted for any other degree in this or any other university.

Supervising Guide
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Place: Ernakulam

Date: 23.04.2024

DEPARTMENT OF PHYSICS

ST. TERESA'S COLLEGE (AUTONOMOUS), ERNAKULAM

M.Sc. PHYSICS

PROJECT REPORT

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DECLARATION

I, SREYA P, final year MSc. Physics student of the Department of Physics and Centre for Research, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project report entitled "**DIGITAL HOLOGRAPHY: A NON-DESTRUCTIVE TECHNIQUE FOR DETERMINATION OF THERMAL EXPANSION COEFFICIENT**" has been originally carried out under the guidance and supervision of **Dr FRINCY FRANCIS,** Assistant Professor, Department of Physics, St. Teresa's College (Autonomous), Ernakulam in partial fulfilment for the award of the Degree of Master of Physics. I further declare that this project is not partially or wholly submitted for any other purpose and the data included in this project is collected from various sources and are true to the best of my knowledge.

PLACE: ERNAKULAM

DATE: 23-04-2024.

SREYA P

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DIGITAL HOLOGRAPHY:

A NON-DESTRUCTIVE TECHNIQUE FOR DETERMINATION OF THERMAL EXPANSION COEFFICIENT

ABSTRACT

In the present work, thermal stress distribution of a few metals is studied and analysed using Digital Holographic Non-Destructive Testing (DHNDT) method. Thermal stress distribution generated along the surface of metal structure are recorded as holograms for various interval of time. The obtained fringe patterns are analysed to determine the thermal expansion coefficient of these metals. These results could be utilized in analysing thermal stress distribution in several manufacturing applications such as aviation and automobile industries where these types of metals are common.

CONTENTS

CHAPTER 1
INTRODUCTION

1.1 HISTORY

A sensor digitizes the recorded interference pattern to produce Holography is a fast-advancing technology for visual imaging. In the 1940s, Hungarian-British physicist Dennis Gabor invented the theory of holography. He is referred to as the "Father of Holography" as well. Following the development of the coherent light source, the laser, in 1960, holography became increasingly important. Emmett N. Leith and Juris Upatnieks, researchers at the University of Michigan, created the first three-dimensional photographs in 1963. Denis Gabor discovered holography in 1948 and suggested using it to increase electron microscopy's resolution (Gabor, 1948). For this achievement, Denis Gabor was awarded a Nobel Prize in 1971. It is a method for "wave front reconstruction" in which a wave front's phase and amplitude are captured. With the advent of the laser and the availability of coherent light sources, holography began to take shape in the early 1960s. When E. Leith and J Upatnieks invented off-axis reference beam optical holography in 1962, it was a significant advancement. A. Lohmann unveiled the first computer-generated hologram a few years later, in 1967. It is possibly an ultimate solution towards three-dimensional view.[1]

1.2 OVERVIEW ON HOLOGRAPHY

In entertainment, science, research, and business all have a lot of benefits from the rapid development of holographic projection technology in recent years. Examples of these applications include scientific visualization, virtual presentations, visual studies etc.

With the advancement of holographic technology, we can create more precise three-dimensional images which is useful in many fields. Holography has a very good future scope that aids us in tedious calculations and studies about many scientific areas and industrial development. Nowadays a digitalized form of holography known as digital holography is developing. Holographic technology in digital form will help us in making calculations easier rather than making them complex. With the help of various applications and software which are capable of doing mathematical operations of the object wave in digital holography enhances its applications in different fields. By the CCD camera and appropriate laser beam, interference patterns called holograms can be recorded. Two images are formed when the hologram is illuminated with reference beam. The obtained two images are real and virtual. A three-dimensional picture that is stored in a laser-generated interference pattern and includes all details about the recorded object's size, shape, brightness, and contrast is called a hologram. Here holographic projections are used to create three-dimensional images to create images that are holograms which is also called holographic technology. A hologram is a wonderful invention as it gives an incredible experience to us when compared to other typical techniques of creation three dimensional images. It appears so original to our eyes. This happens only because hologram can create parallax which helps us to see from different angles with different angular view.[2]

1.3 ANALOGUE HOLOGRAPHY

A hologram recreates a realistic visual image of the three-dimensional objects it captures when illuminated by a coherent source. Similar to traditional photography, holography captures an object's three-dimensional image. Greek words "holo", which means whole or complete, and "gram," which denotes knowledge, are the roots of the English word "hologram". Nearly all the information needed to reconstitute the complete original scene is contained in a tiny area of the hologram. The swift progress of optical, display, and computing technology has revealed a bright future for holography, likely leading to the development of digital holography as well.[3]

1.3.1 PRINCIPLE OF ANALOGUE HOLOGRAPHY

A laser light source that is both spatially and temporally coherent is typically used to record holograms. The reflected laser beam consists of object beam and a reference beam. The object beam which has all the details of the object is complemented by the reference beam. When the two beams are superimposed, an interference pattern is formed on the holographic recording media. The recorded hologram is irradiated with the same reference beam to form an image of the object. The hologram itself act as a diffraction grating which in turn produces the object image.

KEY STEPS:

Important steps in digital holography are given below:

1. **RECORDING:** A coherence beam of laser is irradiated on object. A CCD camera is used to snap the interference pattern formed by the superposition of object beam and the reference beam.
2. **RECONSTRUCTION**: The captured hologram is reconstructed whereby we will obtain the phase and amplitude(intensity) information of the object. From the interference pattern obtained, a three-dimensional information of the object is obtained. This can be seen on a computer screen or other display devices, providing an accurate representation of the form and composition of the object.[4]

A three-dimensional photograph having a particular significance is called a hologram. Same object's two two-dimensional pictures taken from various angles are superimposed to create holograms. Due to the requirement that holography needs a single, exact wavelength of light a laser is necessary. Reflection holograms can be seen in uniform illumination. The object images are captured with the help of a photographic plate and a laser beam. The laser beam is passed through a special filter in order to obtain an expanded beam. Even though the coherence of laser beam is lost its wavelength remains constant. The reference beam is also made to fall on the recording plate. The reference beam and object beam are interfered to form an interference pattern on the recording plate.

Thus, an image is formed on the recording plate. Different observer can observe different image when viewed from different angles. This will provide a three-dimensional view of the object to the viewer. Hologram actually produces an illusion. Diffraction is the process in which white light is allowed to incident on a dispersive element which will separate the light into several wavelengths. Silver plate will reflect the white light it will diffract each wavelength which produces the image having the same colour as that of the object. Thus, we will obtain a three-dimensional image of the object used. The interference between two images gives the hologram.

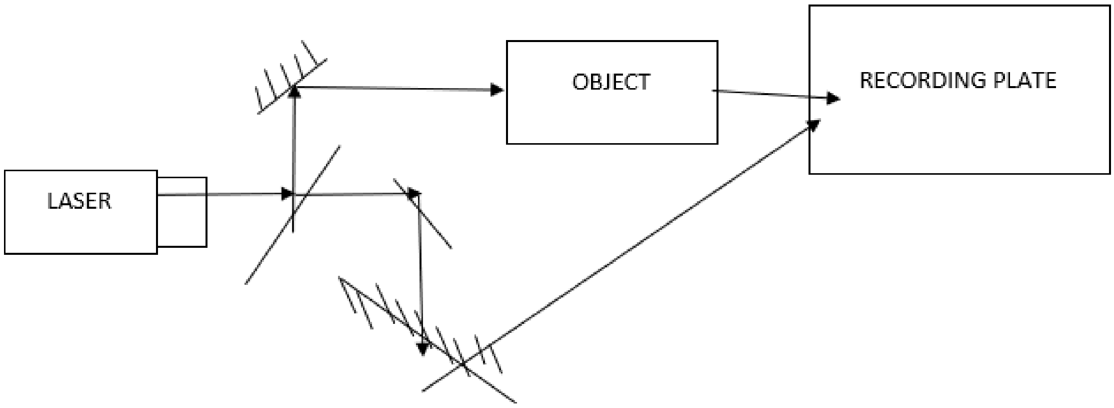

Figure 1.1 Block diagram of conventional holography

1.4 ANALOGUE AND DIGITAL HOLOGRAPHY

Analogue holography employs the method of recording the hologram by the superposition of reference and object beams on a photographic plate. In this method, the reconstruction of the recorded hologram is done by illuminating it with the same reference beam. A Photosensitive recording medium made up of materials such as photoresists, silver halide, photopolymers etc. for recording is an important component of analogue holography.

On the basis of the recording materials used and the image reconstruction method, digital holography varies from analogue holography. In digital holography, an electronic matrix detector which is light sensitive that converts the interference pattern of the obtained hologram into digital information for a computer is used instead of a permanent recording material. Mathematic operations do the reconstruction without the help of a grating material. Recording process is similar in both methods. The use of CCD camera in digital holography can reduce the time consumption in obtaining the image that arises in analogue method. Thus, out of the two methods, digital holographic method is more-easier for analytical purposes. [5]

1.5 APPLICATIONS OF HOLOGRAPHY

Digital holography has numerous applications across various fields:

Microscopy in which biological sample images can be captured at high resolution without requiring laborious sample preparation or staining thanks to digital holography.

Biomedical Imaging: Digital holography is essential to medical imaging because it makes it possible to see tissues and cells without intrusive methods, which helps with diagnosis and therapy tracking.

Industrial inspection: Digital holography is used in manufacturing and quality control to precisely measure and inspect things, including flaws, deformations, and surface roughness. Because of its great precision and non-contact nature, it is perfect for evaluating the integrity of products and componentry.

Displays and Entertainment: Digital holography is a promising technology for the development of cutting-edge display products, such as holographic TVs, augmented reality (AR) goggles, and immersive video games. These apps increase user interest and immersion by taking advantage of the realistic depth perception provided by holographic pictures.

Digital holographic microscopy Digital holographic microscopy is a technique in which digital holography of tiny objects can be obtained. Phase distributions and intensities of microelectromechanical systems and biological specimens can be evaluated using this technique. Due to the absence of reference beam in traditional holography, we cannot evaluate tiny objects accurately. Both university and industrial material science labs employ digital holographic microscopy. Phase imaging of biological cells can also be conducted using this technique. Fundamental biological processes can be studied using this technique.

Digital holographic particle analysis Size distribution, position and speed of micro-particles can be analysed with this technique when these particles are suspended in a fluid. It gives information about volume of the particle. Precise position of particle can be obtained from the reconstruction of various holograms. It is also possible to obtain the phase of the reconstructed object wave using digital holography. Distance travelled by particle is proportional to speed can be produced by either double pulse exposures or laser pulses of a predetermined duration to determine the velocities of the particles. But still these tests demonstrated that lateral and depth resolution are still constrained by the dimension of recording, the wavelength of light, and the distance between the object and the recording device.[6]

1.6 HOLOGRAPHIC NON-DESTRUCTIVE TECHNIQUE

Any technique for evaluating performance that doesn't cause damage to the test object is called "non-destructive testing". Non-Destructive Technique has had unparalleled growth and development in the last 25 years. It is today regarded as one of the technologies that is developing the fastest in terms of novelty and advancement. The assemblies displayed here were designed, engineered, and tested using holographic techniques, which have proven to be the most effective means of evaluating their critical dynamic features.

Holographic interferometry is a potent technique that is highly beneficial for engineering design, quality control, and non-destructive testing and inspection. In Holographic Non-Destructive Testing, a very mild stress or excitation is applied to the item being researched, and Holographic Interferometry is used to observe its behaviour.

One can identify defects in an object by observing anomalies in them otherwise regular fringe pattern. Holographic Non-Destructive Technique is a highly sensitive, whole field, non-contact technique applicable to objects of any size or shape and can be excited by any means mechanical, thermal, pneumatic, or vibrational sources. This can be used to detect defects such as inclusions, fractures, voids, gaps, residual stress, and improper fittings. Holographic Non-Destructive Testing is used to examine things like pressure vessels, rocket casting, PCB inspection, delamination of the composite material of a helicopter rotor blade, and gap between an aviation tire's flies. [7]

Some of the best model and dynamic analysis tools available today are offered by these holographic applications. The system recognizes and shows the displacements, motion geometries, and vibrational modes in real time without causing any harm. Very small amplitude stimulation allows for the study of structures and processed materials, and the data produced can be utilized to increase the precision of structural models that are developed analytically. For the initial design and development of new materials such as graphite epoxy fibre reinforced polymer matrix composites, holographic interferometry is a useful tool. More and more high-tech aeronautical, automotive, and other highly mobile systems are using this kind of material. These defects can be generated by a wide range of structural stresses, including thermal, mechanical, and acoustic stresses, which are otherwise undetectable abnormalities and faults. When deciding on the mechanical configurations and designs, as well as the operating conditions, for buildings made of intricately constructed materials, having this kind of knowledge is frequently essential.

New technological developments in laser and holographic instruments have also greatly boosted the value and usability of these analytical tools. Holographic interferometry has a variety of proven and mature applications in numerous aspects of structural study. The "real-time" and "multi-exposure" holography techniques are the subjects of this discussion. The word “real-time” indicates that, when something is slightly stressed, the hologram of the object is superimposed over the real thing. The phrase “multi-exposure” describes a set of holograms that are frequently generated when there is a difference in stress between exposures for the object under study. [8]

1.7 THERMAL EXPANSION COEFFICIENT

It is defined as the fractional change in dimension of material per unit change in temperature. Coefficient of thermal expansion are of three types, they are linear, areal and volume thermal expansion coefficients. Linear thermal expansion is referred to as change in length of the object with a unit change in temperature. The environment in which the experiment is conducted, temperature and nature of material used determines the value of thermal expansion coefficient. Different materials have different thermal expansion coefficient at different temperature range. From this, we can identify the type of material. Higher the value of expansion coefficient for a given material, greater is the stability of material at high temperature. Thus, material with high temperature can be used in applications where it’s dimension cannot be affected by temperature change. Using these values we can predict the shrinkage in injection model part. [9]

OBJECTIVE

Our aim is to determine the linear thermal expansion coefficient of several unknown metals using digital holography and the observed values will be compared to the literature values and will identify the type of metal.

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CHAPTER 2

DIGITAL HOLOGRAPHIC INTERFEROMETRY

2.1 INTRODUCTION

Digital holography and digital holographic interferometry have a widespread application in various science and technology. This chapter serves to explain about the conventional digital holographic and its application.

Digital holography can be considered as a new technique in general imaging applications. The process of digitally recording and numerically reconstructing holograms is known as digital holography [1]. The photochemical methods involved in traditional holography is eliminated from digital holography which make it more accessible. Digital holography is more-quicker than conventional holography and the wet processing is also not included in this technique. The invention of high-speed processors and CCDs which contains a lot of minute detectors led to the development of digital holography.

Using digital holography, we will obtain both phase and amplitude information about the object. Digital holography consists of two steps which are recording and reconstruction. The superposition of object and reference beams results in the interference pattern in digital holography. CCD camera captures this pattern and is send to a computer which is connected to it. The computer will receive this pattern as an array of numbers. Diffraction theory provides a comprehensive description of the propagation of the optical field, allowing the image to be reconstructed as an array of complex numbers that represents the amplitude and phase of the optical field.

When compared to conventional holography, quick hologram acquisition, the availability of full optical field amplitude and phase information and the versatility of the interferometric and image processing techniques makes Digital holography is more advantageous [2]. The ability to store the holograms for future reconstruction is another merit of digital holography over analogue holography. A major disadvantage of digital holography is the pixel count and resolution of the imaging devices. Main application of digital holography is the metrology of vibrations and deformations.

Particle measurement, 3D object recognition, microscopy, and interferometry are the different fields in which it has been used. using digital holography, pattern recognition and encryption can also be done. in this chapter we discuss about digital holography, its basic principle and its applications [3].

2.2 BASIC PRINCIPLE OF DIGITAL HOLOGRAPHY

A technique for getting all of the information about an object along and across its plane is called digital holography. The two steps of the procedure are to record the wave fronts in the holograms and then reconstruct them. Initially, a digital sensor array is covered with two coherent beams superimposed to create a digital hologram an interference pattern. The information about the object under investigation is stored in the beam known as the object wave, which is created when the incident light from the object scatters. On a CCD sensor camera, the object beam causes interference with the reference beam. The digital hologram is captured by the sensor and saved in a computer for later processing.

The resultant intensity at the hologram plane is represented as follows for complex amplitudes of the reference beam ER and the object beam E_0:

$$I=|E_0+E_R|^2$$

$$I=|E_0^2|+|E_R^2|+E_0^*E_R+E_0E_R^* \text{ .... (1)}$$

Where $|E_0^2|+|E_R^2|$ represents dc term $E_0E_R^*$ represents beam that reflects from the object and $E_0^*E_R$ represents complex conjugate of object beam.

The complex amplitudes of object beam E_0 and reference beam E_R is mathematically represented as:

$$E_0(x, y) = A_0(x, y) \exp (i\phi_0 (x, y))$$

$$E_0(x, y) = AR (x, y) \exp (i\phi_o (x, y)) \text{ .... (2)}$$

The resultant intensity can be obtained from (1) and is written as:

$$I = |A_0|^2 + |A_R|^2 + 2A_0A_R \cos (\phi_R (x, y)-\phi_0(x, y))$$

In this case, the object's amplitude and phase modulations are represented by $A_0A_R \cos(\varphi_R(x,y) - \varphi_0 (x, y))$, where $|A_R|^2 + |A_0|^2$ is the constant dc term. The optical field $E(x,y,0)$

captured by the CCD digital sensor at the hologram plane is represented by the resultant intensity.

Figure.1 illustrates how the object beam and reference beam interfere.

In the second step, a computer performs numerical computation to recreate the wave front that was recorded at the sensor plane as a digital hologram. In order to reconstruct the image, the recorded field E(x,y,0) must be transmitted back to the image plane that corresponds to the object's initial position during the hologram recording at distance "z," as seen in Figure.2.2

A number of reconstruction techniques, including the use of the wavelet transform of the object's real function of amplitude transmission and the approaches of Fresnel, convolution, and Fourier transforms, have been proposed. The wave front is recreated in this instance using the Fresnel diffraction method. Using the Fresnel diffraction method, the reconstructed wave front at a distance "z" in the image can be calculated as follows:

$$E(x,y,z) = \frac{Jk_0 \exp(\exp(-k_0 z))}{2\pi z} \exp\left(\exp\left[\frac{-Jk_0}{2z}(x^2+y^2)\right]\right) FT\left[E(x,y,0)\exp\exp\frac{-Jk_0}{2z}(x^2\ +y^2)\right]$$

In this case, k_0 is the wave number ($2\pi/\lambda$), where λ is the source wavelength, E(x,y,z) is the diffracted field at a distance z in the image plane, and E(x, y, 0) is the complex amplitude of the recorded wave front at hologram plane (z=0). The information contained in the hologram determines the resolution of the rebuilt image. However, factors such as the light source parameter, the recording material's size and spatial resolution, and others affect the information captured in the hologram.[4]

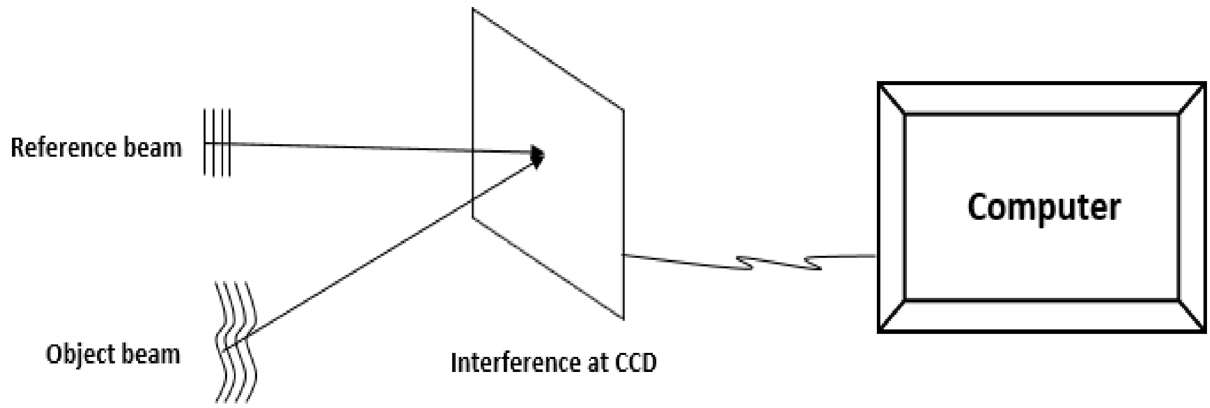

Figure 2.1 -Diagrammatic illustration of the object beam and reference beam interference process at CCD. The digital hologram—a recorded interference pattern is saved on a PC for later analysis.

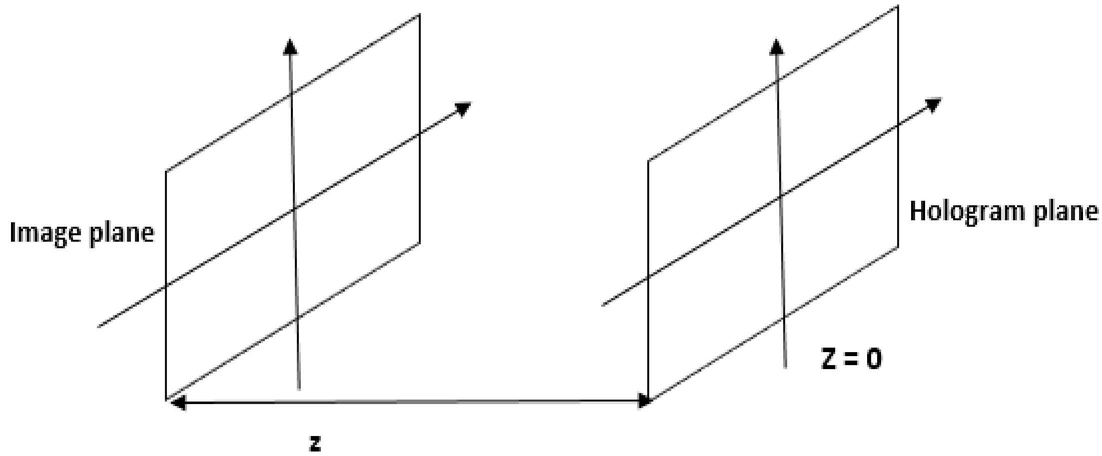

Figure 2.2-Illustration of the hologram and the plane of pictures.

2.3 RECONSTRUCTION AND DOUBLE RECONSTRUCTION

A laser beam which is coherent is incident on a holographic plate which record the interference pattern foe reconstruction. When the interference pattern is illuminated with a reference beam, the entire image of the object is obtained. Then, a three-dimensional image is obtained. This technology can be utilised in museums and exhibitions for reconstruction purposes.

Digital reconstruction is the process in which hologram is recorded digitally. The image is reconstructed by using computational technique. This process consists of a digital sensor, which will snap the interference pattern and the actual image of the object is formed by computational techniques. By double reconstruction we can enhance the quality of the image. It takes two distinct time at which different holograms of the same object is snaped.

Different holograms reconstructed will contain different information about the object. Actual object can be viewed with more clarity using digital holography. So, they are used in field including scientific visualization, microscopy, and holographic displays.

Based on the hologram used and the angle from which it is viewed real and virtual images are formed in holography during reconstruction. A real image is formed due to the convergence of light waves that are reconstructed in space. It occurs when the hologram is illuminated with laser that forms the reconstructed image. An observer can see this image clearly. Image formed has an originality and a depth of information that makes this method accurate.

At the same time, a virtual image is formed behind the hologram. When the hologram is irradiated from the view point of the observer and the reconstructed image is observed without transmitting through the hologram, this happens. Virtual image restores the three-dimensional behaviour like two-dimensional photographs. Ability of holography to display both virtual and real pictures makes it possible for a variety of applications.

Holography can be used to get the three-dimensional image of the object in various fields. Virtual pictures are widely used where accurate imaging and analysis of microscopic or complicated objects are required like holographic microscopy and scientific visualizations.[5]

2.3.1 THEORY OF RECONSTRUCTION

Digital holography includes the following processes: recording a digital hologram, storing it in a computer's memory, and reconstructing it using numerical propagation. Interferometry can make use of this method.

Digital holographic interferometry

Digital Holographic Interferometry is a non-contact, non-destructive technique which can measure the phase differences on the surface of the test object caused by deformations resulting from external loading such as mechanical loading or thermal stress [6]. In digital holographic interferometry, two digital holograms are captured corresponding to two different states of object i.e. before and after the application of external load. The complex amplitude recorded before external loading is represented as:

$$\boldsymbol{E_1(x, y) = A_1(x, y)\,\exp(i\varphi_1(x, y))}$$

where the wavefront's amplitude and phase are captured before to the application of an external load and are denoted by $A_1(x, y)$ and $\phi_1(x, y)$. Following loading, the object's complex amplitude can be expressed as follows:

$$\boldsymbol{E_2(x, y) = A_2(x, y)\exp\,(i\varphi_2(x, y))}$$

where the wavefront's amplitude and phase are recorded following the application of an external load, and are denoted by $A_2(x, y)$ and $\phi_2(x, y)$. The following represents the phase $\phi_2(x, y)$:

$$\boldsymbol{\varphi_2(x, y) = \varphi_1(x, y) + \Delta\varphi}$$

In this case, Δϕ represents the phase shift brought on by the applied external stress. Hence, using the equation above, one can determine the phase variation Δϕ caused by external loading as follows:

$$\boldsymbol{\Delta\varphi = \varphi_2(x,y) - \varphi_1(x,y)}$$

The calculations for $\phi_1(x, y)$ and $\phi_2(x, y)$ are as follows:

$$\boldsymbol{\varphi_1(x,y) = \tan^{-1}\frac{Im(E_1(x,y))}{Re(E_2(x,y))}}$$

$$\boldsymbol{\varphi_2(x,y) = \tan^{-1}\frac{Im(E_1(x,y))}{Re(E_2(x,y))}}$$

values range from -π to π.

Defects on surface of material are identified by digital holographic interferometry as phase changes in the reconstructed wavefront which is related to the deformation. DHI is capable of detecting deformations at sub-micron levels. Although far below the damage threshold, the external loading is high enough to create a fringe pattern. Digital holographic interferometry serves as a direct method for producing interference phase maps. Defects in the object being studied are indicated by irregularities in the interference pattern. Phase maps are therefore employed in DHI to discover flaws. In addition to being used for measuring deformation, it is also used in several fields such as metrology and is employed for form determination, vibration analysis, and measurement of fluctuations in refractive index. The creation of holographic 3D television is another outcome of DHI. [6]

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CHAPTER 3

NON-DESTRUCTIVE STUDY USING DIGITAL HOLOGRAPHY FOR THE DETERMINATION OF THERMAL EXPANSION COEFFICIENT

3.1 EXPERIMENTAL SET UP

The digital holography experimental setup is shown in Figure 3.1. The noise in the laser beam is removed by passing it through a spatial filter using a beam expander. Next, the object under study and the mirror next to it are both subjected to the extended beam.

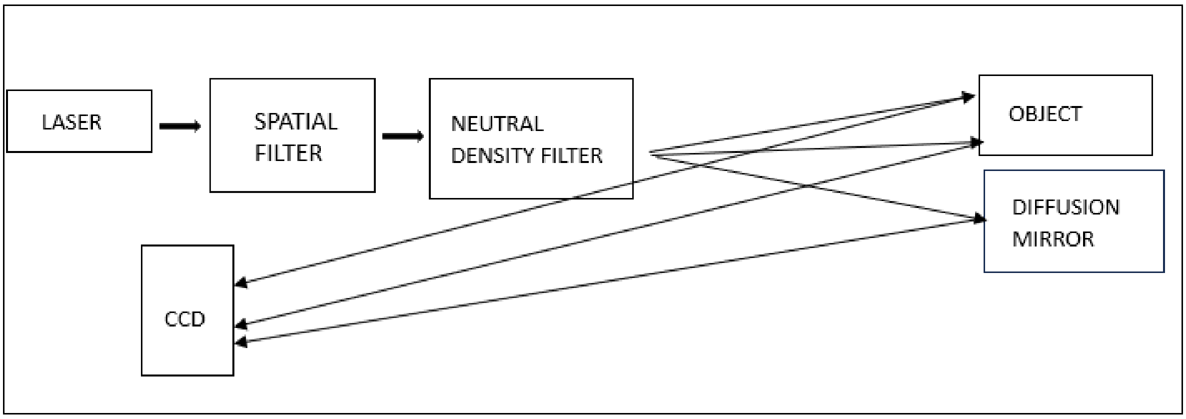


Figure 3.1 – Digital holography experimental set

The reference beam is the beam which is reflected by the mirror and the beam that emerges from the object is called object beam. The object beam and the reference beam should both be pointed in the direction of the CCD camera depending on how the object and mirror are positioned. The CCD which captures interference pattern formed from the two beams and the holograms were captured using the application 'IC-capture'. Next, a PC attached to the CCD which uses numerical methods to recreate the hologram. A software 'H-Digital' has been used to reconstruction the reconstructions which helps us to determine some physical properties of the materials.

Through trial and error, the distance between the item and the CCD was determined to be 73 cm. Single-reconstruction and double-reconstruction are feasible with digital holography. The hologram of object is recreated in a single reconstruction, and the system creates the object's three-dimensional image. Double reconstruction allows for the reconstruction of holograms captured at two distinct times, allowing for the comparison of the conditions of the two time periods. The hologram can be manually recorded, or the program can be configured to automatically record holograms for a predetermined amount of time at predetermined time intervals using a sequence timer. Figure 3.2 shows a view of a hologram prior to reconstruction.

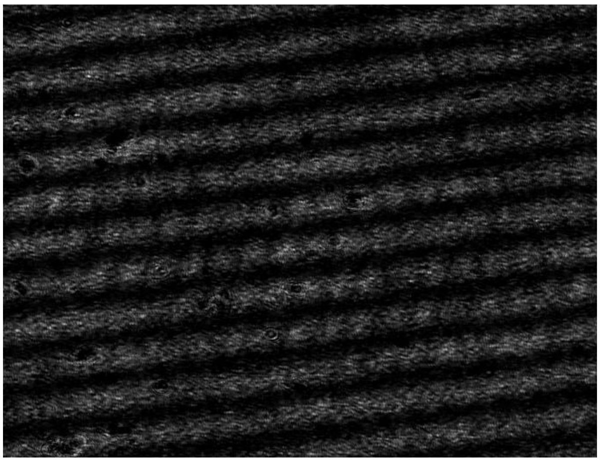


Figure 3.2- Image of hologram prior to reconstruction

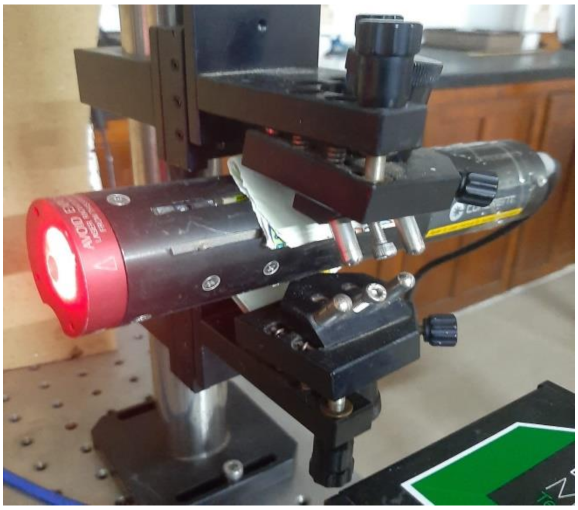
3.2 COMPONENTS USED FOR EXPERIMENT

Typically, a holographic setup has several optical components as listed below. [2]

A. LASER

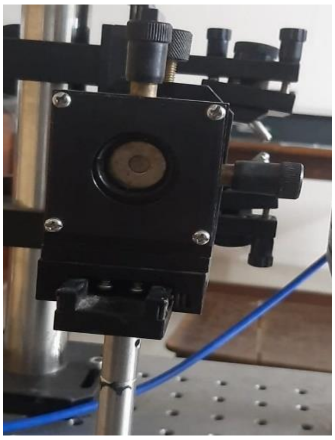
A laser is a coherent source that can create holograms with excellent quality. Helium-Neon (He-Ne), Helium-Cadmium (He-Cd), Argon-ion (Ar^+), Krypton-ion (Kr^+), Diode, and Diode pumped solid state lasers are the most often used lasers in holography. The primary needs of lasers intended in holography are:

i. Extended coherence length
ii. Improved beam quality and reduced noise
iii. Excellent stability and lack of vibration



B. SPATIAL FILTER

The laser beam is spread out using spatial filter. It effectively reduces noise and improves the spatial coherence of laser beam. There is a pinhole and a microscope in a spatial filter. It has a microscope whose objective is to focus laser beam through the pin hole. The aim is to get the necessary beam expansion. Only the intended smooth intensity profile is delivered and higher frequencies which are unwanted are suppressed by spatial filtering.



C. NEUTRAL DENSITY FILTER

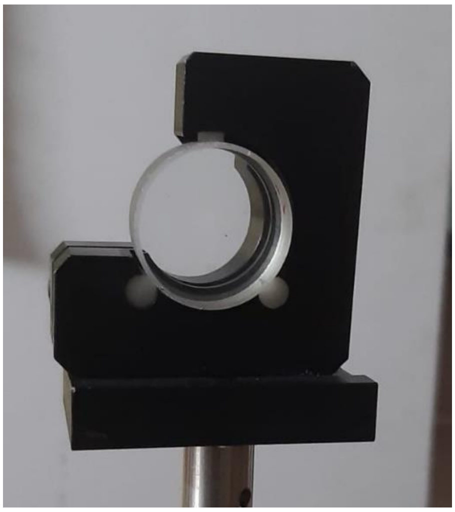
The intensity of output light from laser can reduced to the required value using a neutral density filter. Light from bright sources such as sun can be reduced using grey glasses. Transition metal ions or optical coatings are used in the production of neutral density filter.

D. CCD (CHARGE-COUPLED DEVICE)

CCD represents "Charge-Coupled Device". This kind of image sensor is frequently found in camcorders, digital cameras, and other imaging equipment. When light is converted into electrical charges, which are subsequently transported and read out as a picture, CCDs function. These devices are widely used in fields like scientific imaging and commercial photography because of their excellent light sensitivity, low noise and outstanding image quality.

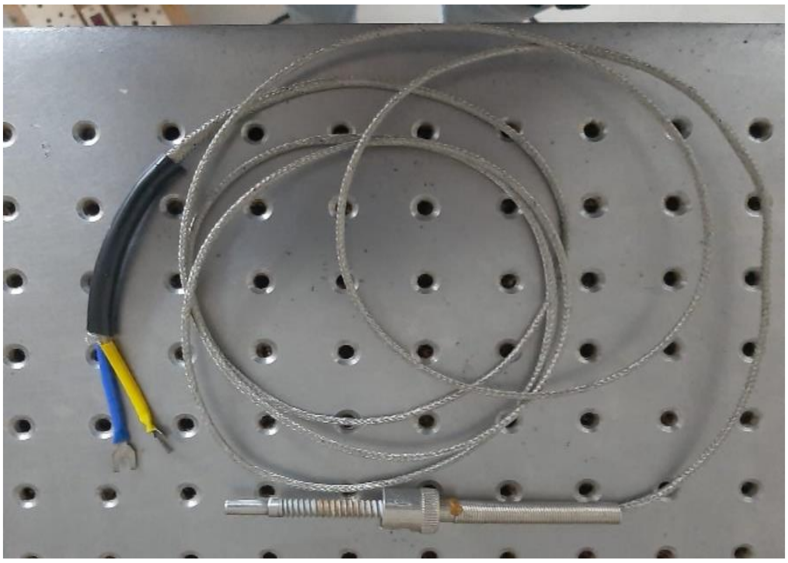
E. DIFFUSION MIRROR

Typically, a diffusion mirror has a translucent or semi-transparent surface that reflects some light and transmit other light. The intensity of light is adjusted as a result of the transmission and reflection working together. Diffusion mirrors are frequently used in photography to generate a soft, even illumination on the subject in combination with artificial lighting sources like strobes or continuous lights.



F. THERMOCOUPLE

Here, we use a J-type thermocouple. It is a temperature sensor composed of two different metals, iron and constantan. These substances provide good precision and stability over a wide temperature range. It is frequently used in industrial and scientific application due to its accuracy and stability in wide temperature range.



G. MULTIMETER

A versatile electronic device used for measuring different electrical properties like voltage, current, temperature, resistance etc.

H. DRYER

A hair dryer used to heat to the sample piece. When a hair dryer is turned on, a heating element such as a ceramic heating element or metal coil is usually heated. The heating effect heats up our sample quickly.

3.3 THERMAL EXPANSION COEFFICIENT

Thermal characteristics of solid materials determines the design of some application processes and technologies. Thermal expansion coefficient can be used to predict the growth of various materials in response to a known change in temperature. Serious structural damage can be expected when the thermal expansion is not considered while designing or constructing a machine or a building. Thermal expansion coefficient can be calculated by measuring the temperature and displacement of a sample undergoing a thermal change. Thermomechanical analysis, interferometry and dilatometry are the three major techniques for finding the thermal expansion coefficient. Interferometric techniques have higher precision than thermomechanical techniques. Since Digital holographic interferometry is a broad field, non-contact, non- destructive method that gives all the required information about the object including its amplitude and phase fluctuations, it is the most important among all interferometric technique. Double exposure principle is used to analyze thermal stress in a non-contact method in digital holography non-destructive technique. Two holograms at two different times of the same object are recorded using double exposure technique. Hence, the object is compared under two distinct situations using the double exposure method. In the current work, the coefficient of thermal expansion has been calculated and the evolution of fringe patterns on heating of several metals used for various applications has been researched. [3]

3.3.1 BASIC PRINCIPLE

In accordance with the Kinetic theory, a rise in temperature is assumed to cause an increase in each atom's kinetic energy, which causes the nearby atoms to push away. Consequently, this leads to a minor increase in the spacing between neighboring atoms, thereby increasing the overall body's size. when a result, the object's size will increase by a specific percentage in each dimension when the temperature rises. There are three forms of thermal expansion based on the type of expansion: linear, area, and volume expansion. The linear expansion ΔL is given by,

$$\Delta L = \alpha L \Delta T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, α is the coefficient of thermal expansion, L is the length of the material and ΔT is the temperature change. From equation 1, α can be written as,

$$\alpha = \frac{\Delta L}{L \Delta T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ΔL is measured from holographic interferometry. It is given by,

$$\Delta L = N\,\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, N is the number of fringes between the temperature range ΔT and λ is the wavelength of the laser source. Substituting equation 3 in equation 2, we get, [4]

$$\alpha = \frac{N\lambda}{L \Delta T} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

3.4 EXPERIMENT

The aim is to study the evolution of fringe patterns on heating and to determine the thermal expansion coefficient of the objects under study. The materials selected for study includes:

1. A rectangular shaped metal piece of length 6.9cm and breadth 3.7cm.
2. A square shaped metal piece of length 5.5cm

(a) (b)

Figure 3.3 - The photograph of object under study, (a) a square shaped metal piece (b) a rectangular shaped metal piece.

The photographs of the objects are shown in Figure 3.3. For making the surface of the object diffusively reflecting, it was painted using white color fabric paint.

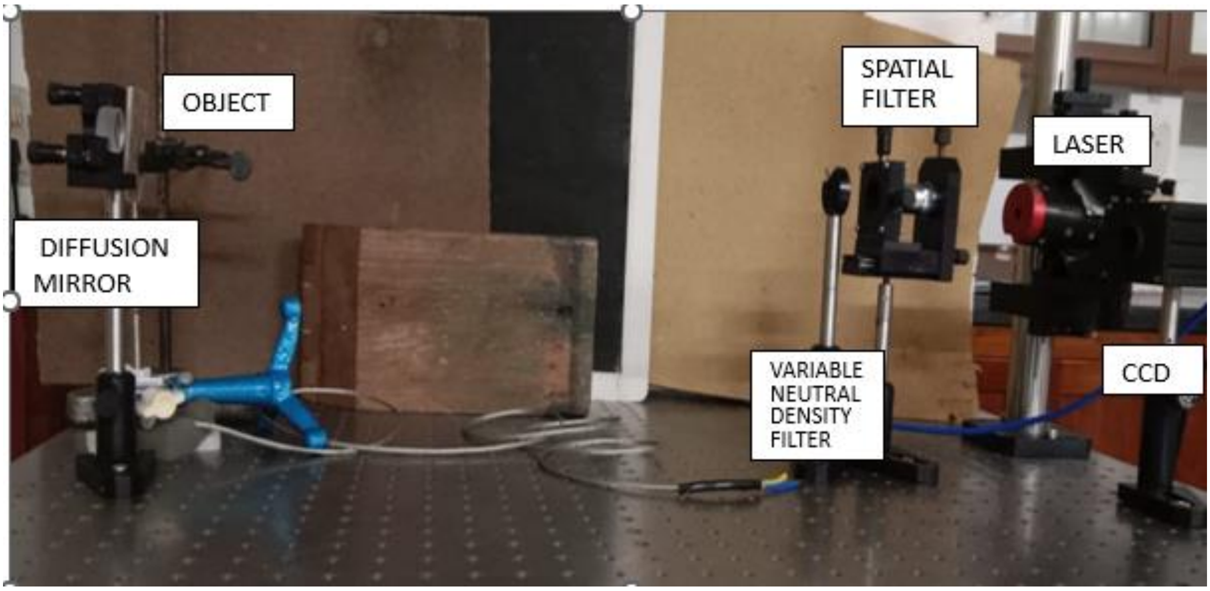


Figure 3.4 – Digital holography experimental set

The holographic set up for the experiment is as shown in figure 3.4. The laser source used for the study was a 648 nm Diode Laser with power 2mW. The light from source was expanded and illuminated the object and the mirror in 1:1 beam ratio. The object was heated using a blow dryer for 15 minutes. The digital holographic software was preset for 15 minutes at an interval of 30 seconds to automatically record the holograms over the cooling time of the object. When two holograms recorded at two different time by an application called IC Capture, instances were reconstructed digitally using a software H-Digital, fringe patterns were obtained which were superimposed on the image of the object. The temperature of the object was measured using a thermocouple arrangement connected with a multimeter.[5]

To measure the temperature using the thermocouple, the thermocouple was connected to a multimeter. Here, Type J thermocouple was used to measure the temperature. And multimeter will display the temperature at different instances.

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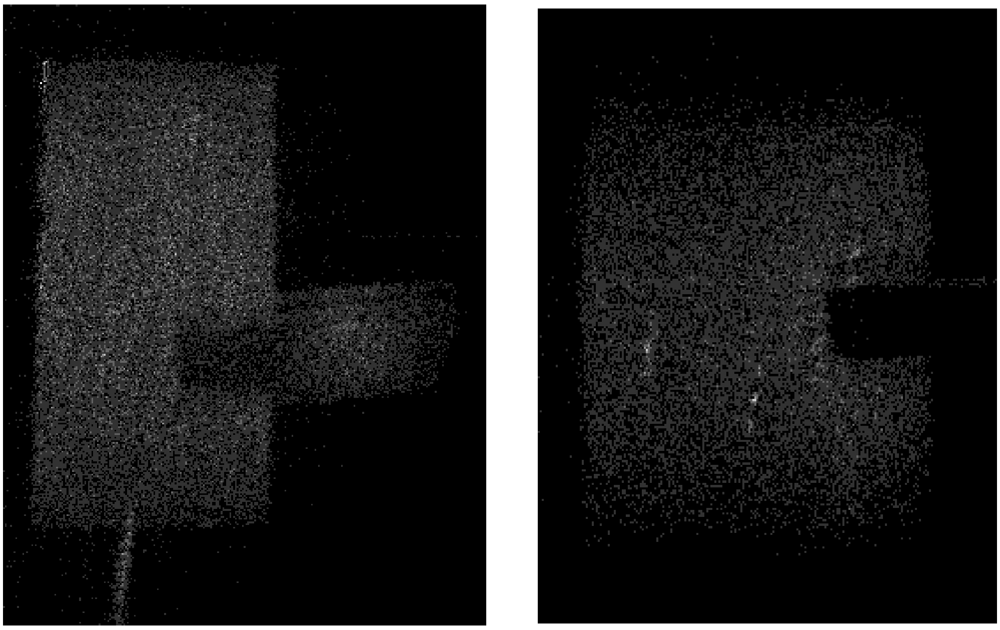
CHAPTER 4

RESULT AND CONCLUSION

4.1 OBSERVATIONS

Sample A was a metal. After heating we captured fringe pattern of object at different instance using IC Capture. Then we assured that we got a clear picture of object by doing single reconstruction using H-Digital as given in the figure 4.1.



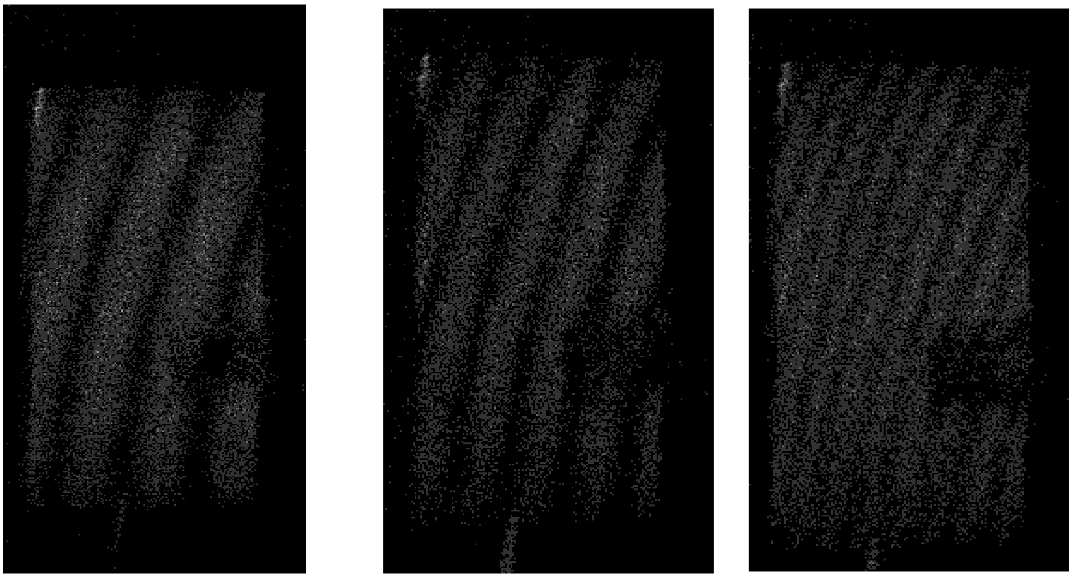
(a) (b)

Figure 4.1- The single Reconstructed image of (a) Sample A (b) Sample B

Then after we double reconstructed fringe pattern of 2 instances (different temperature) and we got a fringe pattern from which thermal expansion coefficient is calculated.

4.1.1 SAMPLE-A

Fringe pattern obtained from double reconstruction of holograms captured at two different instances of Sample A using H-Digital is shown in figure 4.2.



210s and 410s 210s and 840s 60s and 840s

Figure 4.2- The double reconstructed images of Sample A at different instances.

Determined values of thermal expansion coefficient (α) of sample A.

$$\alpha = \frac{N\lambda}{L\Delta T}$$

Wavelength of Diode Laser beam used, $\lambda = 648\times10^{-9}$m

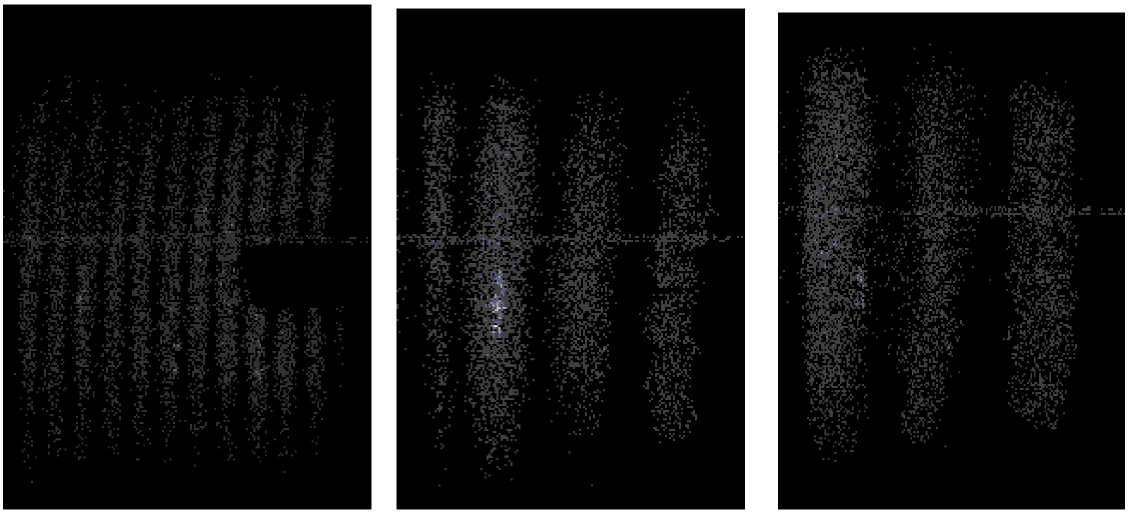
Length of sample A, $L = 6.9\times10^{-2}$m

No. of fringes (N)	Change in Temperature(ΔT) °C	Thermal Expansion Coefficient (α) $^\circ C^{-1}$	Mean Value of α $^\circ C^{-1}$
10	4	23.47×10^{-6}	
7	3	21.91×10^{-6}	23.47×10^{-6}
4	1.5	25.04×10^{-6}	

Table 4.1- Determination of thermal expansion coefficient of Sample A.

4.1.2 SAMPLE-B

Fringe pattern obtained from double reconstruction of holograms captured at two different instances of Sample B using H-Digital is shown in figure 4.3.



30s and 270s   570s and 780s   570s and 750s

Figure 4.3- The double reconstructed images of sample B at different instances.

Determined values of thermal expansion coefficient (α) of sample A

$\alpha = \frac{N\lambda}{L\Delta T}$ Length of sample B, L= 5.5x10^{-2}m

No. of fringes (N)	Change in Temperature(ΔT) ˚C	Thermal Expansion Coefficient (α) ˚C^{-1}	Mean Value of α ˚C^{-1}
11	8	16.20x10^{-6}	
4	3	15.71x10^{-6}	15.35x10^{-6}
3	2.5	14.14x10^{-6}	

Table 4.2- Determination of thermal expansion coefficient of sample B.

4.2 INFERENCE

As the tables above give us the estimated values of linear thermal expansion coefficients, these can be compared with literature values and the sample can be identified. As per the calculation, we found that Sample A has linear thermal expansion coefficient value closer to that of Aluminium which have a standard value of 21x10^{-6} to 24x10^{-6}/^{o}C [3] and Sample B has linear thermal expansion coefficient value closer to that of Steel which have a standard range of 12x10^{-6} to 19x10^{-6}/^{o}C [3]. So, this method can be used to identify unknown metals.

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4.3 GENERAL CONCLUSION AND FUTURE SCOPE

Digital holography is an optical technique that enables the digital reconstruction of holograms that have been optically recorded. Reconstruction using conventional optical holography requires a separate setup. Reconstruction happens more faster in digital holography. As a technique, off-axis DHM is used to get the image of two samples. We can determine the type of material by calculating thermal expansion coefficient using this method.

Image distortion, aberration correction, and depth focus may all be achieved with numerical propagation and digital optics in Digital holography. Digital holography thus becomes an ideal tool foe quantitative, and accurate imaging. Sharp images of the item can be captured by altering the numerical focalization. This technique will enhance the quality of the image by increasing pixels which can be attained from obtaining phase and amplitude of the object. The resolution and contrast of the image will be reduced if scattering occurs out-of-plane. The future scope of this technique depends on development in this arrangement to reduce the scattering.

The linear thermal expansion coefficient of various unknown metals has been measured using digital holographic interferometry which is a non-destructive testing technique. By comparing the results with standard values, the type of metals has been found out. We have to consider thermal expansion coefficient while construction of railroad lines, big bridges, and gasoline pipes. The material with high thermal expansion coefficient should overcome damage and structural changes. As holography is a non-destructive technique object used is not damaged. Because DHI may be used to determine coefficient of thermal expansion and perform non-destructive testing, it can be helpful in identifying unknown metals by comparing their results to those found in the literature.