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Selecting a Nondestructive Testing Method, Part VI: Thermal/Infrared Inspection Techniques – Thermography

INTRODUCTION

Thermography, also known as thermal inspection or infrared (IR) imaging, is one of the most common nondestructive testing (NDT) methods, and it is becoming more widely used as the technology improves and users begin to realize the true potential of this testing method. Thermography is characterized by the use of thermal and infrared sensors to measure temperature variations in a variety of test objects. This article will provide an overview of thermography, including the history, physical principles, inspection requirements, and advantages and disadvantages of the method. [1, 2]

HISTORY AND RECENT ADVANCEMENTS

Despite the long history of thermal inspection methods in noncontact NDT, the potential of thermography as a wide-area NDT method is a fairly recent development. Prior to the development of the infrared camera, thermography was primarily thought of as a qualitative, companion testing method to the more established techniques such as radiography and ultrasonic inspection. Thermography was used as a secondary method to support the primary testing techniques. However, as a result of significant advancements in both IR cameras and software signal processing, thermography has become a stand-alone, effective NDT method. For example, after the Columbia Shuttle accident in 2003, NASA turned to thermography in order to analyze the materials defects that were present on the leading edge of the Space Shuttle (see Figures 1, 2 and 3).[3, 4, 5]

Early Thermographic Techniques

In the 1960s, without the benefit of an adequate infrared camera to remotely detect surface temperature changes, the process of thermographic testing was far more laborious than it is using current techniques. [4] Prior to the introduction of the infrared camera as the primary component in thermal inspection, wide-area testing was the commonly used thermographic technique. Wide-area testing required the test object to be coated with a special temperature-sensitive material. This coating was necessary so that the object needing evaluation could be photographed with a conventional (visible light) camera to obtain a permanent record for analysis. Also, devices such as the evaporograph had to be used to image radiation from the test object onto an oil-coated membrane. This membrane would generate interference patterns that corresponded to temperature variations and could be observed as color changes. Generally, these techniques had slow response times and limited temperature sensitivity. In addition, to achieve maximum performance in a thermal spectral range the test objects had to be heated to extreme temperatures. These factors, combined with the unreliable performance of thermography as a NDT method at that time, were the primary reasons that use of the method was limited. [3, 4]

Figure 1. **NASA employed thermography to analyze defects found on the Shuttle's leading edge. [6]**

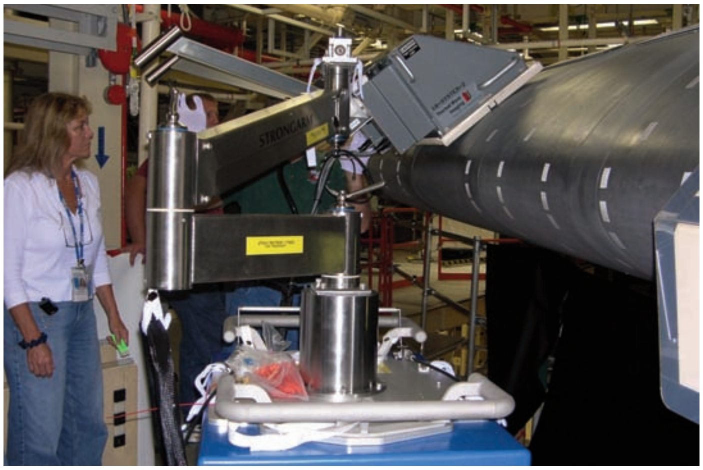

Figure 2. **Thermographic inspection of Space Shuttle leading edge. [7]**

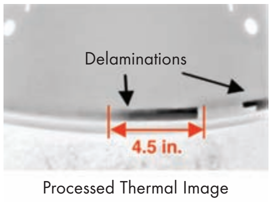

Figure 3. **Delaminations on Shuttle leading edge discovered using thermography.**

Introduction of the IR Camera

Since its introduction in the late 1970s, the IR video camera has been the primary sensor technology used in nearly all thermographic NDT systems. The basic approach used in modern thermographic NDT is to thermally excite the surface of a sample by heating (or cooling) it and then monitor changes in the surface temperature using an infrared camera. This approach is not much different from earlier practices, but the image details that can be produced have improved greatly. Along with improvements in the camera, the adoption of the Thermographic Signal Reconstruction (TSR) method as the primary means of processing and interpreting active thermographic data has led to improved resolution, reliability and quantification in measuring a variety of defects. [3, 4]

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Figure 4. **Thermographic evaluation by mapping local sample points using TSR. [6]**

Thermographic Signal Reconstruction

Thermographic Signal Reconstruction became the commonly accepted approach to processing and interpreting active thermography data in the early 2000s. TSR is a signal processing technique based on the physics of thermal diffusion. Each pixel in the image detected by an infrared camera is treated as an individual time history of cooling behavior at a specific point on the test sample (see Figure 4). The pixel can be converted to an equation that can be used to find specific characteristics at that local point on the sample. This method is similar to an ultrasonic A-scan and further illustrates how thermography has become a primary testing method on the same level as ultrasonic testing and radiography. [3, 4, 5]

In the early stages, TSR was used to create compact, noise-free sequence replicas of flash thermography data. Derivatives of these replicas were used to obtain reference-free evaluation and quantification of results. To detect the presence of a sub-surface defect and to measure defect depth, the derivative of a single pixel time history is analyzed without reference to adjacent pixels. If no defects are present, the derivative can also be used to measure local thermal diffusivity and sample thickness. Modern flash thermography systems are derived from TSR. [3, 4, 5]

Flash Thermography

The most widely used, active mode NDT method is flash thermography. This method is characterized by flash heating of the surface of a test piece by a light pulse that lasts a few milliseconds. Under normal conditions, the part cools after this flash heating and the heat dissipates throughout the part. The heat flows towards the cooler interior at a rate that can be monitored to determine if defects are present. Current flash thermography systems provide precise, highly repeatable measurements of sample or coating thickness and materials properties such as thermal diffusivity or effusivity. Fully automated systems that can be used to collect these measurements have become the new standard in the current NDT environment. [3, 4, 5]

PHYSICAL PRINCIPLES

Thermographic NDT typically involves the evaluation of thermal signatures of the test objects using imaging techniques. Optical excitation techniques, including infrared, are the most common excitation techniques used in thermography. Other excitation methods include radiative heating (examples include: infrared, light, microwaves, electromagnetic induction), mechanical stimulation (sonic/ultrasonic, convection, direct contact), chemical (exothermic reaction of binary adhesive) and electrical (joule heating). These thermal signatures are then used to evaluate various flaws, including leaks, cracks, debonding, corrosion, poor electrical wiring and contacts, and delaminations. They also can be used to assess overall thermal characteristics. The detection of discontinuities in a material is possible because the uniform diffusion of heat from the surface of a sample into its bulk is disrupted by anomalies in the surface properties of the material. When the flow of heat is obstructed, it leads to a non-uniform thermal signature on the sample's surface. This type of heat flow from a part and the corresponding thermal signature are observed and analyzed using thermography (see Figure 5). [5, 6]

Despite the evolution of thermographic equipment and procedures, older methods for thermographic NDT data evaluation are still being used. These practices require the user to watch the data stream as a movie on a monitor or viewfinder and visually identify anomalous areas called "hot spots." This method may prove effective for some applications or types of defects. However, this type of testing methodology does not take full advantage of all the technology available for thermographic NDT. The visual assessment is entirely qualitative, relying on the intuition and experience of the inspector. [3, 4]

In modern thermography systems, the sample is heated by a precisely timed light pulse from a flash lamp discharge. The infrared camera is used to observe surface temperature data as a continuous stream of images that can be analyzed. This data is processed using dedicated algorithms, which enable detection and measurement of features that are not detectable by direct viewing of the video data from the camera. [4, 5]

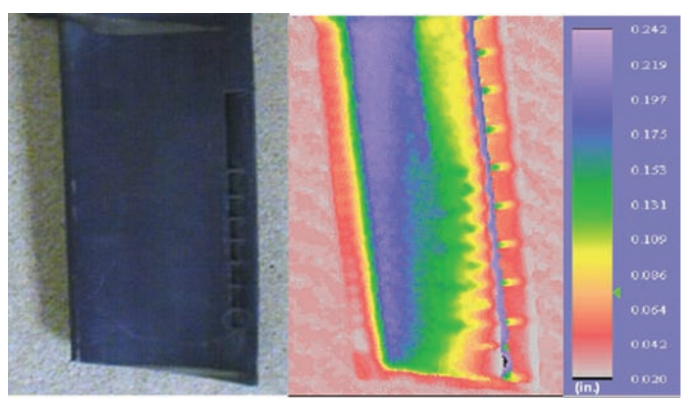

Figure 5. **Thermograph of power turbine blade showing wall thickness. (Photo Courtesy of Thermal Wave Inc.)**

Thermal Property Requirements

It is important to consider a variety of thermal properties in order to determine how the surface of a sample will absorb or emit thermal energy for thermographic NDT. Emissivity, for example, is the ratio of the infrared energy radiated by an object at a given temperature to the energy emitted by a perfect radiator (emissivity = 1), or blackbody, at the same temperature. Therefore, emissivity provides an accurate measure of how efficiently an object emits infrared energy. Since emissivity is a surface property, it is possible to modify the surface of a test object with a low emissivity value by using a high emissivity coating in order to improve the optical absorption and infrared emission of the surface and enable thermographic analysis. For example, bare metals typically require some surface preparation, while most polymer composites used in aerospace applications have sufficiently high emissivity values to enable thermographic testing with minimal preparation. [3, 4, 7]

Another important thermal property to consider when evaluating the applicability of thermographic NDT is diffusivity. Thermal diffusivity is defined as the rate at which heat travels through a material. In some materials that have high diffusivity values, such as copper and aluminum, the heat propagates rapidly, which can be problematic for thermographic NDT analysis because samples may require a higher speed infrared camera. (There are several examples of IR NDT of aluminum in aerospace structures, without the use of high speed cameras. For instance, inspection of the Boeing 737 fuselage and inspection of military aircraft for corrosion have been performed without the advantage of high speed cameras.) The ideal materials for thermographic analysis have more moderate diffusivity values and thus are well suited for NDT because they require standard infrared camera frame rates and conventional infrared radiation sources. Polymer composites typically have thermal diffusivity properties that are conducive to thermographic NDT. Some materials, such as glass and rubber, have diffusivity values that cause heat to propagate too slowly, thus making thermographic NDT an untenable option. [3, 4]

INSPECTION REQUIREMENTS

Advances in TSR have improved the sensitivity and accuracy of the NDT process and removed the reliance on subjective interpretation of the images by operators. This decrease in reliance on qualitative judgments has led to an improvement in thermographic NDT results. Quantitative analysis of the results has paved the way for new developments in the field: thermographic measurement systems. These systems are able to measure other variables, such as defect depth, wall thickness, and thermal diffusivity, with an accuracy nearly equivalent to the methods traditionally used to measure these variables. Such progress is being recognized in the industry and further efforts are ongoing to make thermography equipment capable of more automated functions. As this progress continues, machines capable of defect detection and internal quality control via thermographic nondestructive testing will become more common in industrial applications. [4]

Training

As thermography continues to gain traction in the field of nondestructive testing, standards for inspection and operator training are becoming more common. Currently, it is recommended that inspection technicians be properly certified (Levels I, II, III).

PRACTICAL CONSIDERATIONS

There are many factors that determine whether thermography is an appropriate test methodology for a particular application. Furthermore, it should be determined which mode of thermography offers the best match for the given constraints of a particular application. Thermography is a well-established technique that can be applied in one of two modes depending on the information or type of testing that is desired. The passive mode of thermographic NDT is used for predictive and preventive maintenance, and the active mode is most useful when more detailed information about the internal structure of a test object is desired. Active thermographic NDT techniques are based on analyzing a sample's thermal response to an external excitation. Passive NDT techniques are employed when the test specimen is at steady state conditions. The active approach is much more flexible and is generally characterized by the type of excitation used on the component being evaluated. [5, 6]

Advantages

There are many factors that influence the use of thermography over other nondestructive testing methods. Active thermography is a flexible NDT method that can be applied to a variety of materials or situations, and it can typically be carried out in a matter of seconds after setup. Thermography is a noncontact, noninvasive NDT method that can be used to inspect both curved and flat surfaces (see figures 6 and 7). Also, thermography can be performed on critical parts where only single-side access is available. This means that time and resources can be saved if thermography is used to inspect a part without removing it from the original structure being evaluated. [3, 5, 7]

Disadvantages

Thermography has continually grown in popularity and effectiveness amongst the NDT community, however there are still areas where another method may be more effective. Unlike other test

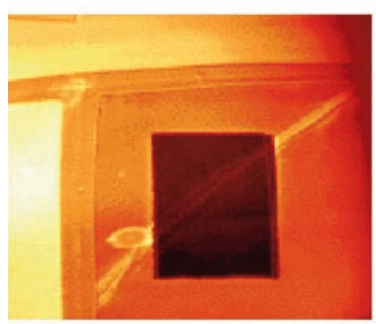

Figure 6. **Thermal inspection of E2-C Hawkeye propeller. [8]**

Figure 7. **Thermal inspection of E2-C Hawkeye aircraft. [8]**

Thermography Summary [1, 2, 3, 4, 5, 7, 9]

Discontinuity types (e.g. what types the method can detect)	• Cracks • Delaminations • Poor Electrical Contacts • Debonding • Corrosion	• Leaks • Thermal Profiles • Adhesive Distribution • Porosity • Wall / Coating Thickness
Size of discontinuities	• Can be determined by aspect ratio	
Limitations	• Infrared camera performance • Hot-spot method is less quantitative	• Aspect ratio of potential test objects • Excitation technique used
Advantages	• Can be used to detect defects in a variety of materials • Non-contact NDT method	• Can be used with limited access to the part • Rapid coverage of large areas
Inspector training (level and/or availability)	• Levels I, II & III	
Inspector certification required	• Understanding the proper way to interpret results is critically important	
Equipment	• Properly chosen infrared camera • Automated systems • Robotic gantry	
Relative cost of inspection	• Varies according to camera used and integrated equipment	

methods, thermography primarily relies on the diffusion of heat throughout the test object. In this case, the energy injected into the sample does not travel in a straight, easy-to-model path throughout the sample as it does in other methods like radiography and ultrasonic testing. Due to this fact, a general guideline for determining the minimum detectable defect size through thermography has been developed. This rule states that the implication of the diffusion process on thermographic NDT is that the size of the smallest detectable discontinuity increases as a function of its depth below the surface. This rule is known as the aspect ratio and a variety of guidelines exist for the exact limit of this ratio. [5] The exact limit that is imposed will vary depending on the excitation technique, the infrared camera performance, the sample material, and the nature of the anomaly. This ratio is not a final determinant of whether thermography can be utilized for a certain application or test material, but it is an effective guide to help users and inspectors make an accurate decision. [3, 4, 5]

Since older methods are still being used in thermographic analysis, the interpretation of the results relies heavily on the inspector. The results are therefore qualitative and can be inconsistent. [3, 4, 5]

CONCLUSION

The thermographic NDT method has continually improved through application and technological developments over the years, and it has become a reliable and commonly used NDT method. As initial perceptions began to change, thermography grew from a companion testing method that was considered less reliable into one of the primary test methods. Thermography no longer requires the subjective interpretation of results or the qualitative judgements of the inspector to produce results. New developments in the field are ongoing as the understanding of what applications are needed for thermographic NDT continues to advance. Over the past few years the development of thermographic signal reconstruction and the institution of automated machines into the thermographic NDT process have led to further improvements and made it easier for the users and inspectors to obtain useful results. From here, the future of thermography looks promising as the once secondary NDT method continues to grow and become more commonly used for finding a variety of material defects. [4, 5, 7]

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