Non-Destructive Ultrasonic Testing of Solid Rocket Motor Casing

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Abstract. *Every engineering application involving the dependent material properties, the structural integrity of the system is conserved by material testing of the system. Various methods applied for the same, they are majorly classified into destructive and non-destructive testing. The involvement of test and assessment technologies to detect any anomalies and characterize the components without damaging or compromising the ability of the component to perform its design function. This report focuses on one of the emerging and efficient non-destructive methods, the acoustic ultrasonic testing on composite made solid rocket motors, analysing internal defects in the system, providing a future baseline for simple and efficient evaluating techniques in the field of non-destructive material analysis.*

Introduction

Early-stage rocket motors using casing materials as Aluminium, Steel M250 etc. with better properties, the advanced ideologies demand more capable materials satisfying least properties like the strength, weight, cost and ease of manufacturing. Composite materials capable of providing the same, emerging manufacturing of the solid rocket motor casing use composites like reinforced carbon epoxy with satisfactory parametric results. Layering or coating a composite is a process involving possible drawbacks of producing defective casing components. Defects causing complete or partial failure of the entire system, naked detection of the defects is a practical challenge. Non-Destructive component evaluation with advanced equipment being necessary as the reputation of casing process will always be unique to itself. Acoustic ultrasonic testing being focused, the process is explained further in the report.

Composite coating over a clay mould of the desired component structure is a process involving the projection of wet resin over the mould to shape the component structure after vaporization to dry the resin. Characterized layer of rubber with variable thickness is laminated over the inner surface of the composite casing to avoid high temperature destruction of the structure during the active propulsion of solid propellant. The thickness of the rubber brings into consideration the instantaneous impulse of the system as the propulsion of solid motors is uncontrolled. The final defective analysis of the component is done using acoustic ultrasonic testing method to load the solid propellant into the structure.

Non-Destructive Evaluation Methods

As mentioned earlier, test and assessment technologies designed to detect and characterize components to perform its design function. This evaluation can include numerous methods to be performed, taking into consideration the application aspect of the same. Noted as one of the effective and efficient methods for the analysis of composite structures, the acoustic ultrasonic testing method evaluates the solid rocket motor casings. However, other non-destructive testing methods include.

(a) Visual Examination and Optical Inspection

Being the oldest inspection techniques, assessment of final form in terms of fabrication accuracy and external features based on experience and decide on their acceptance or rejection. However, few advances with robotic visual inspection have been developed.

(b) Liquid Penetration Inspection

Liquid penetration inspection is a non-destructive method revealing discontinuities that are open to the surface of the solid and essentially non-porous materials. Indications of a wide spectrum of flow sizes can be formed regardless of the configuration at the work piece of flow orientations. Fig. 1 below shows the illustration of the same.

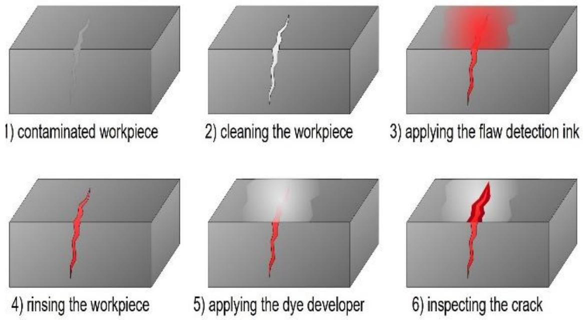

Figure 1. Liquid Penetration Inspection. (5)

(c) Thermal Non-Destructive Evaluation Method

This non-destructive evaluation method is typically based on measurement and analysis of the surface temperature response of a test piece to externally applied temperature or radiational simulations as shown below in Fig. 2.

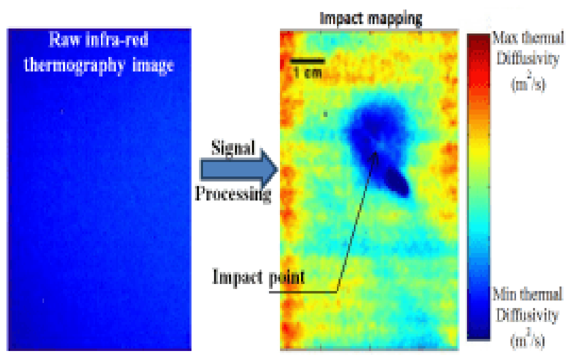

Figure 2. Infrared Thermography of Material. (6)

Unlike thermal process maintaining or preventive maintenance operations, in which the absolute temperature of the part is measured under steady state conditions, the thermal non-destructive evaluation methods extract information about the subsurface state of the part from its transient response as it is excited from or returns to a quasi-equilibrium state.

Numerous other methods of non-destructive evaluation have been recently discovered for unique applications. One such special technique most suited for the application of defect analysis in the solid rocket motor casing, the acoustic ultrasonic testing method is followed as described below.

Acoustic Ultrasonic Method

Ultrasonic inspection is a family of non-destructive methods, in which beams of high frequency mechanical waves are introduced into materials, using transducers, for the detection and characterization of both surface and subsurface anomalies or flaws in the material. The mechanical waves travel through the material with interfaces and discontinuities including flaws and other anomalies. Response signals are detected, displayed and then analysed to give signatures that are used to define the presence, location and other anomalies, characteristics of flaws and discontinuities. The degree of transmission or reflection depend largely on the physical state of the materials forming the inner face and to lesser extent on the specific physical properties of the material. Any kinds of anomalies that produce reflective interfaces, and which are large compared to the wavelength of ultrasound can easily be detected. Partial reflection or reflection of the ultrasound waves can detect voids, inclusions and other inhomogeneities. The ultrasound inspection instruments detect flaws by monitoring the following:

(a) Reflection of ultrasound from interfaces consisting of material boundaries or discontinuities within the material itself.

(b) Velocity of waves that control the time of transit of an ultrasound wave through the test piece.

(c) Alteration of ultrasound waves caused by absorption and scattering within the test piece.

(d) Features seen in the spectral response for either a transmitted ot reflected signal.

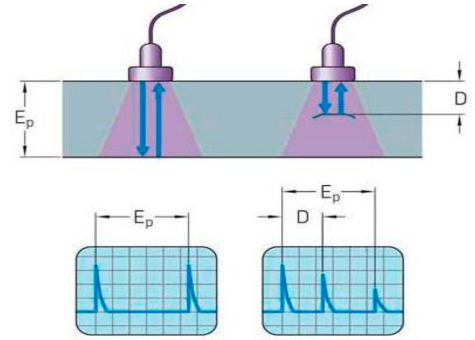

Figure 3. Ultrasonic Testing of Material Sample. (7)

On an average, most ultrasonic inspections are performed using frequencies between 10 KHz to 400 KHz. The stresses imposed by these mechanical waves on the structural parts are fairly below the elastic limit of the components, hence preventing any permanent effects on the parts.

Experimental Procedure for Ultrasonic Inspection of Solid Rocket Motor Casing

As described, the ultrasonic inspection of analysis allows the use of same verified component for the actual use, being a method of non-destructive testing. The method is applied after the resin structure formation and layered rubber insulation of the rocket motor structure. The insane size of the motors is sectioned into numerous divisions both longitudinally and along the circumference to manually test each section with the ultrasonic equipment. The transmitting probe and the receiving probe of ultrasonic testing equipment are firmly held on the surface to be examined to obtain the condition of material between the points. For an ideal material section, the oscilloscope for the system shows a pattern of a typical progress in amplitude along time.

The pulsating transmission by the transmitter causes a series pattern of the waves with a time gap of 't' seconds. The pattern obtained for each section of the casing is matched with the reference wave pattern produced for an ideal material by means of either simulation of practical proved material sectional analysis. Any relative changes in the pattern represents an anomaly over the respective region as displayed in Fig. 4.

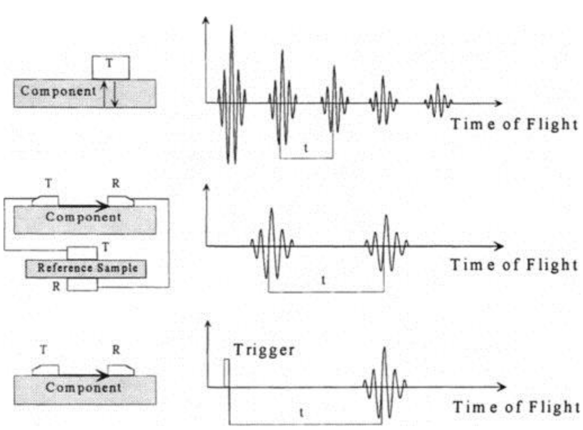

Figure 4. Ultrasonic sound patterns in Testing. (8)

Conclusion

The non-destructive method of ultrasonic testing provides a precursor to the valuable data determining the structural integrity of the system prior to actual usage, avoiding major unnecessary implications of the system and proves to be successful for the composite solid rocket motor casing analysis.

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References

[1] K.Srinivas, J.Srinivas, V.G. Tiwari, N. Sudarshan, "Acousto – Ultrasonic Technique for Bond Quality Inspection of Solid Rocket Motors". https//www.researchgate.net (2021).

[2]R.Nagappa. "Evolution of Solid Propellent Rockets in India". Defence Research & Development Organisation, Ministry of Defence, India. 2014.

[3]"Nondestructive Evaluation of Materials". Volume 17. 2018.

[4]S.Subhani, "Quantitative Thermal Wave Detection and Ranging for Non – Destructive Testing of Solids". 2019.

[5]Tec-science, "Dye Penetrant Inspection (DPI)", 13 July 2018, https://www.tec-science.com/material-science/material-testing/dye-liquid-penetrant-inspection-dpi/ . (Last accessed: 21.09.21).

[6]i-composites lab, "Non-Destructive Techniques – Infra-red Thermography (IRT)", http://www.mub.eps.manchester.ac.uk/i-composites-lab/facilities/ndt/ . (Last accessed: 21.09.21).

[7]J. Hallback, "Non-Destructive testing at SKF", 31 March 2017, https://evolution.skf.com/en/non-destructive-testing-at-skf/ . (Last accessed: 21.09.21).

[8]Schneider, E., and V. Hauk. "Structural and residual stress analysis by nondestructive methods." *Amsterdam: Elsevier* (1997): 522-