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Quality Assessment of High Strength Metallic Rocket Motor Casings - A Non Destructive Testing Approach

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***Abstract* - Advanced Launch vehicles and missile systems use solid rocket motor casings as their primary propulsive systems. The design, manufacturing and testing of these systems are performed in accordance to the most stringent standards. In order to gain high specific strength, ultra-high strength materials like Maraging steel are used. The quality assurance methodology for such material is arrived keeping in mind the material's fracture behaviour. Such systems are required to perform in the presence of miniscule flaws and when subjected to internal/external loads since complete elimination of defects/flaws in uneconomical. The quality control strategy is principally aimed at avoiding/eliminating defects that may lead to catastrophic failure during service. Non Destructive Testing (NDT) has been the empowering tool for defect detection and disposition in all aerospace applications. Stage by stage implementation of NDT is required to ensure quality and integrity of the hardware. Perfection in manufacturing is the obvious goal, but since this cannot be absolutely achieved, NDT must exercise the highest degree of reliability that can be obtained from techniques, equipment and personnel. This paper highlights the prominent NDT techniques viz. Radiographic inspection, Ultrasonic inspection and Acoustic Emission inspection used to assess the quality of rocket motor casings. The abilities of the testing, the relevant standards and stage of usage are discussed.**

***Index Terms* - Quality Assurance, NDT, Rocket Motor casing**

I. INTRODUCTION

Solid Rocket Motors serve as the propulsion back-bone for strategic and tactical missiles as well as satellite launch vehicles [1,2]. Solid propulsion becomes overwhelming choice because of its inherent safety, high reliability, handling ease, simplicity, high density impulse, minimum maintenance and integration. Ultrahigh strength metallic material like maraging steel are extensively used for realizing rocket motor casings[3]. The shells and the end domes of the rocket motor casing are fabricated from sheet metal &shells interconnected with rings which are machined suitably from ring rolled forgings and welded. The individual raw material and components undergo rigorous NDT to ascertain quality. In spite of a planned NDT in place, advent of defects is inevitable. 100% elimination of defects is as impossible as is uneconomical. Hence critical defects that may cause failure have to be identified and eliminated. Generally the rocket motor casings fabricated may need to be stored for several long years before being put into use. Hence that appropriate methodology which ascertains the quality of the rocket motor casing so that it performs its function optimally at the end of the service life/storage period is to be adopted. Such a methodology comprising of various NDT methods to have a strong quality assessment of rocket motor casings is discussed in this paper.

II. QUALITY ASSURANCE BY NON-DESTRUCTIVE TESTING

Non-destructive Testing (NDT) is a very broad, interdisciplinary field that plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective approach. NDT testing defines and implements tests that locate and characterize material conditions and flaws that might be less visible, but may hamper the structural integrity. The NDT techniques that have to be used need to be finalized vis-a-vis to the design process. The acceptable defect sizes are arrived based on structural analysis and fracture based design approach. The type, size, orientation, and location of the rejectable flaw are often correlated to a code, standard, or requirement. Based on these inputs, the desired NDT methods shall be carefully chosen so as to ascertain quality. During the manufacturing process, the NDT methods have to be used in tandem in a way where defects of lower order are not apparent to the higher order NDT methods [4,5].

The rocket motor program employs a detailed and comprehensive program of material and fabrication-process control throughout material procurement and fabrication. This program permits detection of potential causes of failure and the timely repair and correction of these areas. Proper Quality inspection processes are key factors in the success of this approach.

The development of a successful non-destructive testing (NDT) plan are outlined in six steps [6]. Briefly, these six steps are as follows:

(1) Determine the types of defects that require detection
(2) Evaluate existing inspection (NDT) techniques for sufficient sensitivity and accuracy or develop new acceptable or adequate technique
(3) Verify that the inspection techniques obtain a valid indication or description of the actual defects
(4) Establish accept-reject standards for each type of defect and each inspection technique
(5) Establish an inspection plan
(6) Eliminate any redundant inspection as knowledge and experience are gained during case development and production

The inspection plan shall incorporate inspection processes for use from initial material procurement through case final acceptance to the extent necessary to maintain a specified reliability level. Inspection processes (NDT) should encompass material procurement and continuing through fabrication, process control, and final acceptance. Each phase can use different inspection techniques with different acceptance or rejection standards. The scope of the NDT plan should be established on the basis of the required reliability level, the type and orientation of defects encountered, and the process sensitivity required.

In high-strength-material applications, the minimum inspection process recommended is the use of radiographic and ultrasonic, and dye-penetrant inspection of weld, and ultrasonic and dye-penetrant inspection of the parent material. Appropriate inspections should be made after critical events (i.e., heat treatment and hydrostatic test). The detection capability of each process used should be known from past experience or should be demonstrated by tests, using the production equipment, materials, and process sensitivity [7].

For example, if a sheet is rolled and welded, then after rolling, Liquid penetrant (LPI) test is used to eliminate all surface bound defects. Immediately after welding radiographic testing (RT) is carried out to eliminate defects that are volumnar in nature. The next higher order method to be used shall be Ultrasonic testing (UT) to eliminate all tight cracks and planar defects. If in case LPI is not carried out at the first-cut, then most of the surface indications shall give rise to echoes during UT inspection. To avoid such an anomaly, NDT methods shall be always used in the increasing order of detectability. In adopting the above methodology, the structure is left with only those defects that are deemed to be acceptable. Inspite of these efforts, it is possible that the defect due to its orientation/stress favourable position may try to grow on application of stress. To detect such defect growth and to eliminate critical /active defects online methods viz. Acoustic Emission testing is used during acceptance tests like load/pressure tests. The NDT examination adopted in several stages and brief description of them are given below:

Stages of Fabrication	Material prior to Fabrication	After Welding	After Heat Treatment	During Proof Pressure Test (PPT)	After Proof Pressure Test
NDT Method	VI, LPT, RT & UT	VI, LPT, RT & UT	VI, LPT, RT & UT	Online AET	VI, LPT, RT & UT

VI - Visual Inspection
LPT - Liquid Pentrant Testing
RT - Radiography Testing
UT - Ultrasonic Testing
AET - Acoustic Emission testing

III. LIQUID PENETRANT TESTING

Discontinuities open to the surface such as cracks, cold shuts, laminations, through cracks or lack of fusion is indicated by Liquid Penetrant method. In general, liquid penetrant is evenly applied over the surface of the part being tested and the penetrant effectively wetting the surface of the specimen, flowing over the surface and then migrating into the cavities that are open to the surface. After a suitable dwell time, the excess penetrant is removed and the part dried. This leaves a clean surface of the component with penetrant residing in the discontinuities. A developer is then applied which draws the entrapped penetrant out of the discontinuity, staining the developer. The test part is then inspected visually to determine the presence or absence of indication. The test shall be carried out as per ASTM E 165 and no surface defects like porosity and cracks open to surface shall be permitted at sheet level/forgings/after welding/after heat treatment/after Proof pressure test.

IV. RADIOGRAPHY TESTING (RT)

X-ray and gamma rays are used in radiographic testing. These are electromagnetic radiation of very high energy and very low wave length which allow them to penetrate in the material. These are absorbed as they penetrate the material. They are differentially absorbed if there is any variation in the material. Due to differential absorption, different intensities are getting transmitted out the specimen and transmitted radiation carrying information of the specimen is allowed to fall on a recording medium to form a shadow image or silhouette image. Radiography can easily detect volumnar defects like porosity, lack of fusion, lack of penetration etc. It is one of the essential methods to certify the weld soundness. It also provides a permanent record of discontinuity presence on the component.

As per Aerospace requirement, the radiographic films used comply with specific configurations. Fine grained films (D4) are used for radiography. The films are ensured to be free from all mechanical and chemical damages. The density of the radiograph should range between 2 to 4. All the radiographs to have an image quality indicator. The film is kept as close as possible to the material to be radiographed. The Source to Film distance (SFD) is less than 20 times the thickness and shall not exceed 1 meter under test. The radiographic technique is in such a way that the sensitivity of the radiograph is better than 2% of the base metal thickness. Accordingly, suitable penetrameter shall be used. Penetrameter shall be placed on the surface of the weld that is nearest to the radiation zone. The material properties of the penetrameter are same as that of the material under test.

Forgings (Raw Material)

Forging lips after machining are radiographically tested to eliminate agglomerations / seggeregation defects.

Weldments

100 % radiographic examination is carried out as per ASME B & PV code Section VIII Division 2, Article 1-5. The procedure and acceptance criteria for radiographic examination are as follows:

- Cracks, lack of penetration, under cut, piping (elongated porosity) and lack of fusion etc. are not permitted.
- Isolated porosities shall be permitted, if the diameter of the porosity is less than 10% of the thickness of the base metal provided the distance between two porosities are as follows:
- The distance between two isolated porosities along the weld shall be equal or greater than 5 + t/4 mm(t = thickness of the base metal).
- Total length of the defects to be repaired should be less than 5% of the total length of weld bead. Isolated porosities and tungsten inclusions in the weld bead within 25mm from either end is not permitted. Dark images of circular or oval shape shall be interpreted as porosity.
- Tungsten inclusion to the extent of porosity acceptance is allowed.

The same procedure & acceptance criteria is followed for post Heat Treatment and post hydrostatic pressure test inspection.

V. ULTRASONIC TESTING

Bars (Raw material)

Each slab is subjected to ultrasonic inspection as per SAE AMS 2630B and acceptance level is class A (2.0 mm Flat Bottom Hole).

Sheets (Raw material)

The sheets are manufactured by consumable electrode melting and are supplied in cold rolled, solution annealed and descaled condition. The sheets are subjected to ultrasonic inspection as per SAE AMS 2632A. The Acceptance level is selected from various notches from the following table. The requested notch is decided design inputs. The reference notch shall be made on welded plate / plate of the thickness equivalent to that of the object being inspected.

S.No.	Type of Notches	Size in mm
1	E	1.02 X 0.52 X 0.25
2	F	0.26 X 0.76 X 0.25
3	G	2.52 X 1.26 X 0.25

Forgings

All the raw materials are supplied in solution annealed condition in accordance with AMS 2759/3C.Ultrasonic test is conducted as per SAE AMS 2630B and the acceptance Criterion is Class A1 (1.2mm FBH).

Weldments

The weld is flush ground on penetration side as well as reinforcement side for ultrasonic test. The test is carried out as per ASTM E 164.The Acceptance level is as mentioned above.

Ultrasonic Inspection of thin Welded Sheets

SAE AMS 2632A shall be followed for Ultrasonic inspection of thin materials (13mm and thinner). Selection of the reference defect size i.e. E/F or G notches are chosen as a result of Fracture based design process. Recording of all defect indications above 50% of DAC with regard to assigned reference notch is carried out.

The acceptance criteria is taken as follows :

- Reference reflector -As mentioned above.
- Single discontinuity response – 100% and less
- Multiple discontinuity response – 50% and less (Two or more indications separated by a distance equal to or less than 15mm)
- Linear discontinuity response – 50% and less

The same procedure & acceptance criteria is followed for post Heat Treatment and post hydrostatic pressure test inspection.

VI. ACOUSTIC EMISSION TESTING

Acoustic Emission is an Online Technique used for monitoring of Structural Integrity of rocket motor casings. The AE parameters acquired during testing reveal presence of critical defects or growth of sub-critical growth. AE signals requires a through/in-depth investigation of AE parameters as and then they are acquired. Certain important parameters are established based on laboratory level experiments and literature [1,8]. Hence online monitoring of graphs corresponding to such parameters is sufficient. Too many graphs/data representations may slow down the efficiency of acquiring and hence may end up in a "acquisition lag". The important graphs to be monitored are as below :

1. Location Graphs
2. Time Graphs
    a. Amplitude Vs Time
    b. Count Vs Time
    c. Energy Vs Time
3. Hit Rate for each sensor
4. Count Rate for each sensor
5. Cumulative Vs Time Hit Graph

The acceptance criteria for maraging steel rocket motor casings based on AE data is developed using various specimen level studies, trial tests on actual rocket motor casings and burst tests. This acceptance criteria is given as

Kaiser Effect is to be observed (to be checked during recycling)
Hit Rate <= 1.5 Hits per sensor per second (throughout testing)
Count rate <= 100 counts per sensor per second (throughout testing)
No continuous High amplitude, high count hits (throughout testing)
Amplitude <= 70 and Counts <= 500 (during hold periods)

During AE testing the above parameters have to be checked and any deviations from these should be followed with an immediate hold period. In case of persistence of deviation, the test should be aborted and offline analysis is to be carried out to find out the sources of the emissions and also to check the integrity of the motor. The identified defective locations have to be thoroughly checked again with other NDT techniques.

VII. CONCLUSION

Non-Destructive Testing techniques play a vital role in Quality Assurance of High strength steel Rocket motor casings.NDT methods have to be used systematically for fool-proof detection of defects. For fracture prone materials, incorporation of on-line NDT test viz. Acoustic Emission Testing is essential to ascertain growth of sub-critical defects and to indicate presence of critical flaws that lead to catastrophic failure. The respective NDT methods shall be implemented in keeping with the Guidelines prescribed in the relevant standards (as mentioned) and applicable codes.

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