

Impact and Manufacturing Defect Visualization of Space Launcher Aluminum Liner/Filament Wound Composite Fuel Tank using Ultrasonic Propagation Imaging System

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ABSTRACT

We applied ultrasonic propagation imaging (UPI) system for rapid and reliable quality control of fuel tanks for a space launcher. The fuel tank is an aluminum-lined CFRP propellant tank. The UPI system uses Q-switched laser (QL) to generate ultrasonic wave on the test specimen, and laser mirror scanner (LMS) to control the laser impinging point that scans the area of interest with high speed. Each ultrasonic wave generated by laser impinging was received by a piezoelectric sensor with coordinate information of the scanned area. After ultrasonic propagation image processing, results with impact damage and manufacturing defect information of the fuel tank were presented.

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INTRODUCTION

Space launcher structures should be manufactured to meet the designed performance on each part with various materials. One of important design issue is its lightweight for high economic efficiency. Weight reduction on launcher structure increases capacity of the launcher with the same weight and also decreases fuel consumption when it is launched. Consequently to reduce the weight of the structure, the use of advanced composite materials is steadily increased in aerospace industry due to the high strength-to-weight ratio of composite materials.

In case of compressed fuel tank, it consists of a liner and composite overwrap to achieve high compression performance. When a compressed tank is made with only composite materials for ideal lightweight structure, it cannot hold pressured liquids or gases because composite materials have high permeability. Therefore, a liner was essentially needed for compressed tank to prevent leakage. The liner was usually made with polymer or metal. In consideration of the desired containment pressures, polymer liners are used in low pressure, and metal liners are used in high pressure.

For high pressure containment, aluminum-liner/CFRP wound tank is typically used.

Due to its lightweight and high performance value, application areas of composite compressed tanks are expanded to medical, military, and transportation. However, composite materials always have inherent defect from manufacturing process. This defect causes a performance reduction of structure. Therefore, stringent quality control programs are needed to ensure the successful performance and safety of structures.

As a quality control technique for composite materials, conventional X-radiography, pulse-echo, through-transmission, infra-red thermography and dry coupling ultrasonic test techniques have been applied during various manufacturing stages. During the conventional X-radiography test, we should ensure safety of inspector from radiation and carefully manage and store radiation materials. Similarly, other techniques also need additional process. But, it is hard to get the reliable results from these techniques on the complex structures and they also cannot support high speed inspection. Consequently, slow inspection speed results in delay in the manufacturing period that decrease cost efficiency in all of the processes.

In this paper, we have developed a high speed quality control system based on the ultrasonic wave propagation imaging (UPI) system for compressed fuel tank of space launcher structures. [Figure 1](#) explains the UPI system which

consist of a Q-switched laser (QL), laser mirror scanner (LMS), ultrasonic sensor, sensor system and computer.

A Q-switched laser (QL) generates ultrasonic wave on the specimen, and the laser mirror scanner (LMS) controls the laser impinging point that scans the area of interest with high speed. A piezoelectric ultrasound sensor receives all of the ultrasonic waves with coordinate information of the scanned area. After ultrasonic propagation image processing, the scanning results were presented such as ultrasonic wave propagation image (UWPI), anomalous wave propagation image (AWPI)[1], USI, WUPI[2], ToF map[3], VTWAM and wave length estimation.

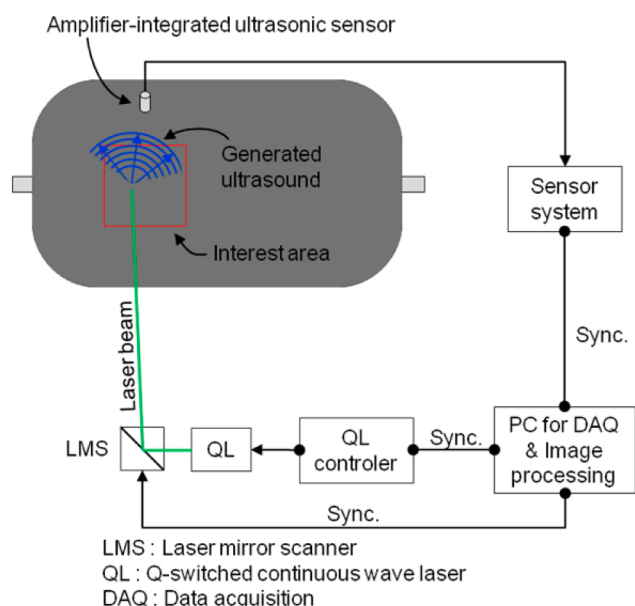


Figure 1. Schematic diagram of laser ultrasonic wave propagation system

The UPI system provides high speed inspection which depends on the laser pulse rate frequency (PRF). The 1kHz PRF supports the complete scanning of 40,000 points (200mm×200mm scanning area with 1mm interval) in just 40 seconds.

ALUMINUM LINER/FILAMENT WOUND COMPOSITE FUEL TANK

In consideration of desired performance of compressed tank, designers decide materials of liner and composite with the required length, and thickness, also select manufacturing process of liner such as by weld assembly or seamless liner. During the composite winding process several other factors are considered such as: wind the liner with wet winding or impregnated winding, helical winding angle and width of filament of winding pattern, etc.

During the manufacturing process, quality control is needed on liner and final product to ensure good performance of the structure. As a quality control system, a nondestructive evaluation technique should be devised to detect the internal flaw of the tank, because it is difficult to detect any flaws on the internal side of the product.

The filament winding is classified as wet winding or impregnated winding depend on the state of tow. The wet winding need resin bath for impregnation of the tow during winding process. So it is easy to store the filament spools and resin. However, perfect impregnation is difficult to control in resin bath. Therefore wet winding process easily leads to the air void in tow.

The impregnated winding called prepreg, use fabric tape which is already impregnated thin tow film with resin to accurately control the performance of product during manufacturing. Therefore prepreg process don't need a resin bath on the winding machine and reduce air void defect. However it is necessary that prepreg tape be kept carefully on non-stiffening temperature. Thus, working hours will be limited depending on the resin stiffening time.

During both winding processes, tow or prepreg is wound in the liner along the winding pattern under uniform tension. This tension can effect to the core condition, if tension is out of control, it causes the core damage. In the helical winding process, tow overlaps each winding that cause the crossover points. At these crossover points, void and core damage are expected due to the undulation on tow wound section. While controlling the winding interval if the winding speed is not stable, it causes the gap or overlapping between tow wound. This causes a crack to occur easily along this gap and also imbalance can be found along the overlapping.

In addition to these manufacturing defects, short core, bond separation of core node, lack of adhesive, porosity, potting crack and delamination are found on the composite wound.

However in the filament winding process, these manufacturing defects cannot be avoided. Therefore, defect density evaluation is required as a quality control to ensure the perfect performance and safety of the composite tank.

Specimen

Specimen is an aluminum-lined CFRP propellant tank shown in [figure 2](#). The tank has a seamless aluminum liner which has 3mm minimum thickness at center of cylinder portion then increased to 4mm at the end of cylinder portion. CFRP wound has 5mm thickness on cylinder portion which includes 1mm thickness of prepreg hoop winding, 2.5mm thickness of 9 degree prepreg helical winding and 1.5mm thickness of wet hoop winding. Additionally less than 0.2mm thickness is present from GFRP wound and epoxy coated without sanding surface.