NDE2002 predict. assure. improve.
National Seminar of ISNT
Chennai, 5. – 7. 12. 2002
www.nde2002.org

ULTRASONIC EVALUATION OF MULTILAYER BONDS (COMPOSITE / CERAMIC CEMENT / METAL) IN ROCKET THRUST CHAMBERS

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ABSTRACT

Thrust chamber and Nozzle are critical functional parts in a Rocket Propulsion system. The nozzle region of rocket consists of layers of different materials. Quality of these materials as well as their interfaces have to be ensured. In certain cases these materials can be evaluated independently before bonding to form the multi layered product. But in the case of certain ceramic/insulators (like ceramic cement preparation), they are formed into a layer only during the assembly operations. Thus, it is not possible to characterize or evaluate the material individually before assembly. This paper describes the development of the methodology and application of an ultrasonic non-destructive evaluation process for the materials and interfaces after assembly of the multi layered elements.

1.0 INTRODUCTION

Rocket nozzles are usually made of layers of materials. Generally, there are outer structural member followed by a thermal insulator layer and an inner ablative material for low erosion and ablation against the flow of hot gases (fig.1). In most cases, the inner ablative material and the metallic outer structure are evaluated in raw material stage and at other processing stages by various means. However, when the insulation material is made of ceramic cement it has to be formed during the assembly operations. Thus, this part of the nozzle is unavailable for independent characterisation and evaluation. Non destructive means can be used for in situ evaluation of these products. Ultrasonic NDE methodologies are very effective for such applications.

The properties of interfaces between metallic hardware and ceramic cement, ceramic cement and nozzle throat etc are required to be evaluated before use. Ultrasound can be used for studying the interfaces because the reflection of ultrasound from the interfaces depends on the quality of bond between these interfaces.

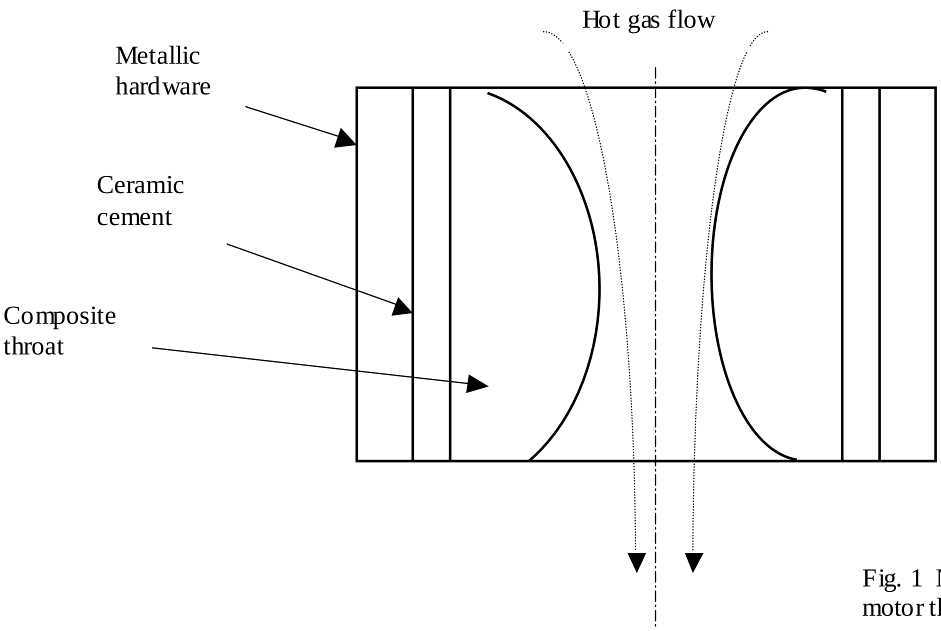

Fig. 1 Nozzle of rocket motor thrust chamber

2.0 DEVELOPMENTAL STUDIES

Coefficient of reflection of sound intensity $R = (Z_2 - Z_1)^2 / (Z_1 + Z_2)^2$ (1)

Coefficient of transmission of sound intensity $T = 4. Z_1 . Z_2 / (Z_1 + Z_2)^2$ (2)

Where Z(impedance) = velocity x density,

Z_1 & Z_2 are impedances of material 1 and 2 respectively. From the equations 1 & 2 , it is clear that at perfect bond conditions the reflection and transmission at interface of two materials is dependent on the material quality also. When the bond quality is poor (low strength / minute debonds at interface), there will be additional reflection because there is no perfect contact.

Developmental studies are conducted to understand the possible variation of the reflection / transmission coefficient due to ceramic cement process variation during assembly. The fig. 2 gives the variation of sound velocity in ceramic cement measured for different ramming time (an important process parameter) on specimens. As the velocity changes, the impedance of ceramic cement changes. Measurement made on controlled sample at extreme velocities indicated that the identification poor bond / debond is feasible.

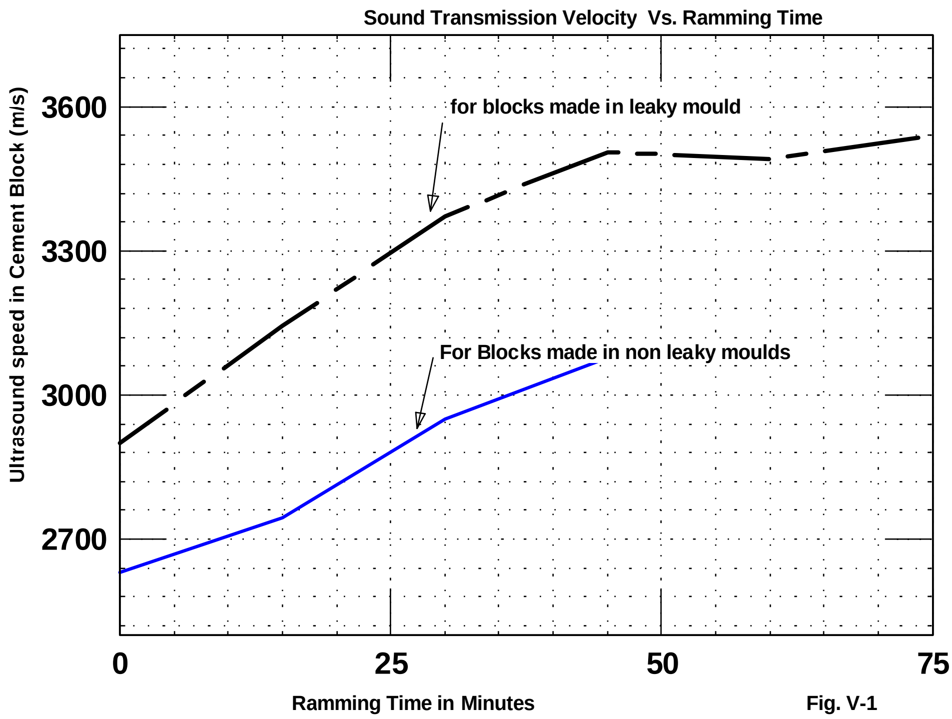

Fig. 2 : Variation of sound velocity due to ramming time change during ceramic cement specimen preparation. Note:- The variations are given for both leaky moulds(water is leaking from the mould) and non leaky moulds(water is not leaking from the mould)

3.0 FEASIBILITY STUDY:

Studies are conducted to understand the following aspects of the non destructive evaluation of these interfaces and materials.

i. Transmission of sufficient sound energy through the combination of materials.
ii. Inspectability of the product in shop floor conditions.
iii. Interpretability of results for useful purposes (clear identification of bond quality like good bond, poor bond and debond).
iv. Identify the stages of inspections

Several specimens with combinations of the materials of interest were prepared and evaluated using ultrasound frequency 4MHz and below. It is found that the material combination can transmit any frequency 4MHz or below. But, when frequencies of 4 to 2 MHz are used, small variation in material at certain localities may affect the transmission to a great extent due extensive scattering of high frequency portion of spectrum. This may affect interpretation of the result to locate debond.

During the studies to assess the inspectability of the product, it is found that there is sufficient approach for moving the transducers inside the structure and outside. Thus both through transmission and single probe inspections are feasible. Since throat material is sensitive to conventional liquid couplant dry couplant probe (transducer) faces(developed in house) can be utilised for these combination of materials.

The results are interpretable because the normal surfaces condition has no major impact on the results. That is, a poor bond will be interpreted as poor bond only, even in the worst conditions of surface. Studies revealed that inspection can be done after solidification of the ceramic cement insulation layer. (The data collected are on dummy / trial products of launch vehicle under use)

4.0 TRANSDUCER SELECTION:

Frequencies between 1 MHz and 0.5 MHz are found more suitable. In through transmission inspection, the studies revealed that the detectability of the dedebond depends of the probe in the throat side(inside) (fig. 3) . Hence, for better detectability smaller size probe is used on throat side and bigger probe is used on outside

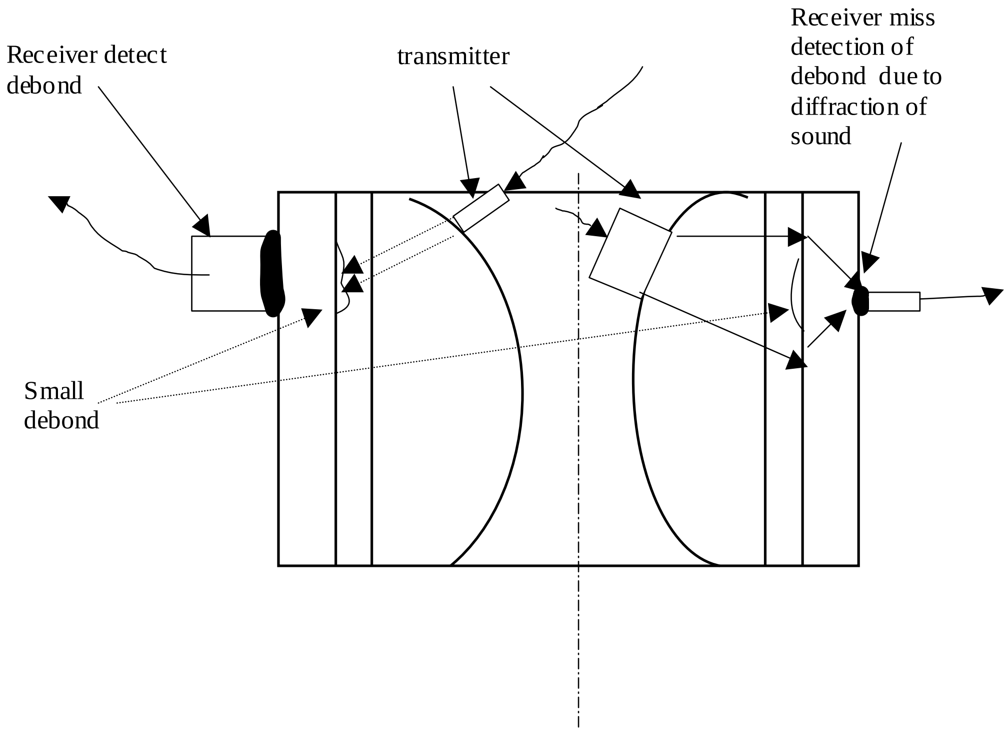

Fig.3 : Detectability of small debond due to probe selection.

In single probe inspection, from outside metallic hardware, the detectability of the interface quality of metal/cement depends on the amount of sound signal that can be transmitted through cement. If the cement is of low quality due to excess pores, sound signal of high frequency part of transducers will not be transmitted to the cement, hence poor bond may be interpreted as total debond. Thus frequency of lowest possible range (ie. 0.5 MHz) is to be used for grading the quality of bond.

5.0 DEVELOMENT OF APPLICABLE PROCEDURE

Procedure was developed with details of transducers to be used at various situations and locations of the product for better delectability of the defects. In this procedure guidelines has been given for coordinated movement of the transducers in through transmission inspection. Reference specimen was designed and fabricated with known defects for calibration purposes.

6.0 APPLICATION ON PRODUCT

Large number of products are evaluated using this methodology which enabled to detect even process variation during bonding process. It also helped to generate data on the effect of certain welding, mechanical activities etc on the hardware on bond quality. This data helped the production agency to take necessary precaution during fabrication in order to prevent deterioration of bond quality due future operations after bonding operation.