NEW ULTRASONIC STANDARDS

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ABSTRACT

Standard samples containing defects of known size, shape, and location are requirements for the evaluation and calibration of NDE test equipment. Here we review the methods developed for producing such samples from selected metallic alloys and ceramics. In the work with metallic alloys, the method of diffusion bonding Ti-6Al-4V is presented in some detail and is illustrated for a large number of samples containing a variety of defects ranging from spherical cavities and inclusions, to prolate and oblate spheroids, to thin discs and simulated cracks. In the work with ceramics, the method of hot pressing of glasses with cavities and inclusions is illustrated for a variety of defects. The presentation demonstrates how these samples may be applied in a procedure for calibrating ultrasonic systems by employing a recently proposed characteristic equation for the system and a figure-of-merit for the transducers in analogy to the gain of a radar antenna.

Figure 1 suggests a new approach to ultrasonic standards for use in the calibration of ultrasonic systems. The approach focuses attention on "calibration standards" exclusively, and introduces a single equation which characterizes the ultrasonic system and allows a step-by-step accounting of the effect such as those from transducers, material availability, etc.

The equation shown in Fig. 2(a) (ultrasonic range equation) gives a detailed accounting of all of the steps involved, from the transmitted electrical signal all the way through the scatterer to the received electrical signal. A calibration procedure is demonstrated which achieves a calibration by comparing the experimentally determined parameter, $S_{experimental}$, to its independently obtained and invarying counterpart, $S_{theoretical}$. This is demonstrated in Fig. 2 under the heading of "Calibration Procedure" and here we show a comparison over a range of scattering angles through experimental $(S)_{dB}$ values which are shown in data point open circles and theoretical expectation values to solid lines, One can see that you get very good agreement for this particular demonstrating experiment. Figure 2(b) is a photo of the fixture used to calibrate the ultrasonic system. It shows, in detail, the polygonal sample of Ti-6Al-4V alloy with a apherical tungsten carbide inclusion. Also shown are the typical commercial transducers used in the experiment. To get the graph shown in Fig. 2(c), we have to carry out the detailed calculations indicated in Fig. 2(a) for the ultrasonic range equation. The new standard is obtained by inserting a scattering target in a solid medium by using diffusion bonding or analogous techniques. This is demonstrated in Figs. 3, 4, and 5.

Metallurgical Aspects of Diffusion Bonding

In order to produce ultrasonic reference standards for calibration purposes, samples were diffusion bonded as shown in Fig. 3(a) and some of the types of defects in defect arrays are shown in Figs. 3(b) and 3(c).

The bonding process is illustrated in Fig. 4 with stringent requirements on lapping, cleaning, and diffusion bonding methods in order to create a bond with no defects or impurities, and yet produce a sound diffusion bond without gross deformation in the sample which would cause a change of shape of the defect. The sample assembly is also shown in Fig. 4, along with defects of varoious geometries that have been fabricated.

Figure 5 illustrates some of the requirements in the diffusion bonding process where calculations have shown that good surface preparation is essential to obtain a metallurgically sound bond at low pressure so that distortion of the desired defect is avoided. In order to calculate the desired bonding pressure and bonding time, elevated temperature flow stress measurements are made on the material out of which the sample is to be produced.

Figure 6 illustrates some of the measurements that have been made on ceramic standards. These are produced by fabricating a sample with a sphere of either nickel or some other suitable material inserted into a glass matrix. Advantages of such processes are low cost, low attenuation, low noise from the ceramic sample, and optical transparency in the glass so that the location of the defect can be found independent of the ultrasonic measurements. The overall philosophy is thus to use a target similar to a sphere in a water bath with the advantages and convenience of portability and application to shear wave calibration. The standard can be adapted to both pulse echo and pitch methods. The approach introduces a new figure-of-merit for transducers (a factor G) in analogy to the gain of the radar antenna. Thus, scattering theory plays an all-important role, because: (1) it can be introduced into the software to normalize out transducer characteristics, (2) it describes "defects" in terms of scattering cross sections, and (3) it has transferability between laboratories and inspection stations.

What we have done is defined in Fig. 7. The calibration standard is an ultrasonic standard solely employed to insure equipment is functioning according to specifications, and is in distinct contrast to the so-called reference standard which is simply a library of scatters of different shapes used to aid in the identification of an unknown defect after ultrasonic systems have been calibrated. The objective of this work has been to develop an overall system calibration and to develop a technique that has sufficient dynamic range so that systems can be calibrated and compared to theoretically known expectations. The new feature is the ultrasonic range equation, which encourages separation of transducer effects, material reliability effects, propagation losses, and scattering in standard defects. It introduces the concept of a self-consistent calibration, i.e., the use of an additional independently-determined invariant parameter against which a system can be calibrated. It also suggests new procedures in materials for fabricating essentially material-independent calibration standards, and introduces a concept of transducer G factor as a figure-of-merit in analogy to antenna gain in radar, and, finally, it permits the theory as an aid in primary standard calibration and an aid in developing software for accurate ultrasonic testing and system calibration.

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SUMMARY

THIS POSTER SUGGESTS A NEW APPROACH TO ULTRASONIC STANDARDS FOR USE IN THE CALIBRATION OF ULTRASONIC SYSTEMS.

THE APPROACH FOCUSES ATTENTION ON "CALIBRATION STANDARDS" EXCLUSIVELY, AND

INTRODUCES A SINGLE EQUATION WHICH CHARACTERIZES THE ULTRASONIC SYSTEM AND ALLOWS A STEP-BY-STEP ACCOUNTING OF EFFECT SUCH AS THOSE FROM TRANSDUCERS, MATERIAL AVAILABILITY, ETC.

A CALIBRATION PROCEDURE IS DEMONSTRATED WHICH ACHIEVES A CALIBRATION BY COMPARING AN EXPERIMENTALLY DETERMINED PARAMETER, S_{exp}, TO ITS INDEPENDENTLY OBTAINED AND INVARIANT COUNTERPART, S_{th}

THE NEW STANDARD IS OBTAINED BY EMBEDDING A SCATTERING TARGET IN A SOLID MEDIUM BY USING DIFFUSION BONDING OR ANALOGOUS TECHNIQUES

THE TARGET IS THUS SIMILAR TO A SPHERE IN A WATER BATH WITH ADVANTAGES IN CONVENIENCE, PORTABILITY AND APPLICATION TO SHEAR WAVE CALIBRATION

THE STANDARD CAN BE ADAPTED TO BOTH PULSE-ECHO AND PITCH-CATCH MODES

THE APPROACH INTRODUCES A NEW FIGURE-OF-MERIT FOR TRANSDUCERS, THE "TRANSDUCER GAIN FACTOR G," IN ANALOGY TO THE GAIN OF A RADAR ANTENNA

SCATTERING THEORY PLAYS AN ALL IMPORTANT ROLE BECAUSE IT:

(1) ALLOWS THE DEVELOPMENT OF SOFTWARE TO NORMALIZE OUT TRANSDUCER CHARACTERISTICS
(2) INTRODUCES THE SCATTERING CROSS SECTION
(3) HANDLES RIGOROUSLY MATERIALS TRANSFERABILITY AND VARIABILITY

Figure 1. New approach to ultrasonic standards for use in the calibration of ultrasonic systems.

ULTRASONIC RANGE EQUATION
(ANALOGOUS TO RADAR RANGE EQUATION)

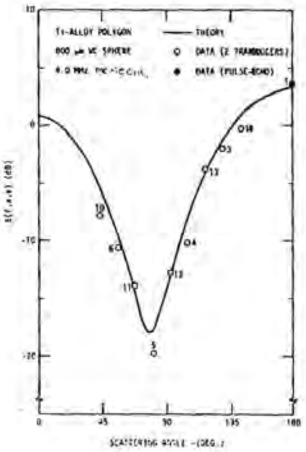
$$(A_R)_{dB} = (A_T)_{dB} + (G_T)_{dB} + (P_\ell)_{dB} + (S)_{dB} + (G_R)_{dB} + (F)_{dB}$$

$(A_R)_{dB}$ - RECEIVED ELECTRICAL SIGNAL AS SEEN ON CRT
$(A_T)_{dB}$ - TRANSMITTED ELECTRICAL SIGNAL
$(G_T)_{dB}$ - TRANSMITTER TRANSDUCER G-FACTOR
$(P_\ell)_{dB}$ - PROPAGATION LOSSES
$(S)_{dB}$ - SCATTERING FUNCTION
$(G_R)_{dB}$ - RECEIVER TRANSDUCER G-FACTOR
$(F)_{dB}$ - GAIN OF RECEIVER AMPLIFIER

a

CALIBRATION PROCEDURE

COMPARISON OVER A RANGE OF SCATTERING ANGLES BETWEEN THE EXPERIMENTAL $(S)_{dB}$ VALUES (DATA POINTS) AND THE THEORETICAL EXPECTATION VALUES (SOLID LINE)

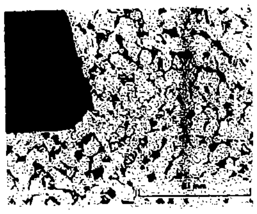


c

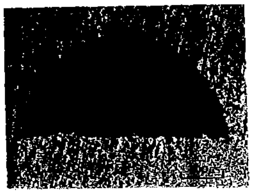
PHOTO OF FIXTURE USED TO CALIBRATE ULTRASONIC SYSTEM
(1) COMMERCIAL TRANSDUCER
(2) POLYGONAL SAMPLE OF Ti-6Al-4V ALLOY WITH SPHERICAL TUNGSTEN CARBIDE INCLUSION (0.080 cm DIAMETER)

Figure 2. Ultrasonic range equation, calibration fixture, and calibration procedure.

THE BOND LINE (ARROWED) IS METALLURGICALLY INDISTINGUISHABLE FROM THE BASE METAL.



ULTRASONIC REFERENCE STANDARDS PRODUCED BY THESE METHODS HAVE ACCURATELY CONTROLLED DEFECT SHAPES. A HEMISPHERICAL DEFECT IS SHOWN BELOW.



SINGLE HEMISPHERICAL DEFECT MAGNIFIED 100X

SERIES OF DEFECTS IN A FRACTURE SURFACE

ARRAYS OF DEFECTS CAN BE READILY PRODUCED BY THE DIFFUSION BONDING PROCESS.

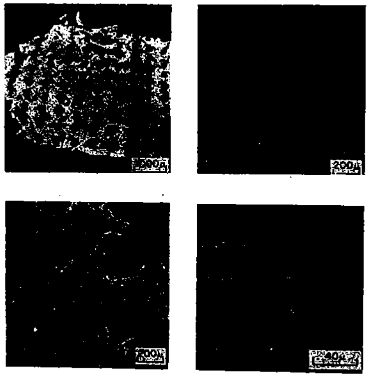
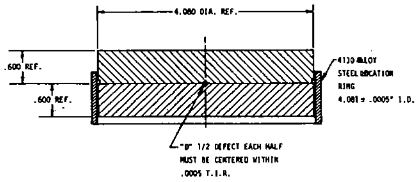


Figure 3. (a) Diffusion bonded sample; (b) and (c) types of defects and defect arrays.

THIS TABLE SHOWS THE SURFACE PREPARATION AND DIFFUSION BONDING PROCEDURES USED FOR Ti-6Al-4V.

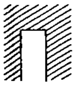
LAPPING	SURFACE GROUND AND LAPPED TO 4 FINISH FLAT TO WITHIN FOUR OPTICAL BANDS.	
CLEANING	1. WASH IN ACETONE	
	2. WASH IN ALKALINE CLEANER 80-100 C	15 MIN.
	3. RINSE IN DISTILLED WATER	3 MIN.
	4. PICKLE 68% BY VOLUME HNO_3 58% g/LITER NH_4F HF BALANCE H_2O	
	5. RINSE IN RUNNING DISTILLED WATER	3 MIN.
	6. PASSIVATE 50% HNO_3	1.5 MIN.
	7. RINSE IN DISTILLED WATER	3 MIN.
	8. AIR PRESSURE RINSE	
	9. RINSE IN DISTILLED WATER- 6 TIMES	1-2 MINS. EACH
	10. OVEN DRY - 90-120 C	15 MIN.
DIFFUSION BONDING	1. HEAT IN VACUUM OF BETTER THAN 10^{-5} TORR TO SPECIFIED TEMPERATURE (900 OR 926 C).	
	2. LOAD TO 500 psi FOR 30 MINS.	
	3. COOL IN VACUUM.	

SAMPLE ASSEMBLY FOR
4 INCH DIAMETER SPECIMEN

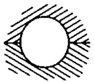


NDE DEFECT SAMPLE ASSEMBLY
FINISHED DIMENSIONS 4.000 ± .002 in DIA.
1.000 in HIGH
MATERIAL Ti-6Al-4V HEAT # D4705B (ORMET)

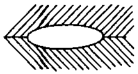
DEFECTS OF VARIOUS GEOMETRIES HAVE BEEN FABRICATED



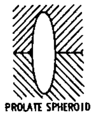
FLAT BOTTOM HOLE
TYPE 1 DEFECT
400 800 1200μ DIA.



SPHERICAL CAVITY
TYPE 2 DEFECT
400 800 1200μ DIA.

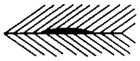


OBLATE SPHEROID
TYPE 3 DEFECT
800μ DIA.
200 400μ HIGH



PROLATE SPHEROID
TYPE 4 DEFECT
1600μ HIGH
400 800μ DIA.

PENNY SHAPED CRACK
TYPE 5 DEFECT
1200 3000μ DIA.



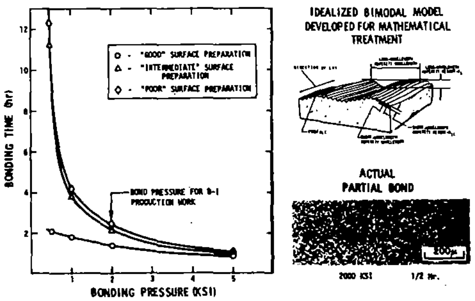
SIMULATED CRACK
TYPE 6 DEFECT
1200μ DIA.

DEFECT GEOMETRIES USED IN THE PROGRAM

Figure 4. Illustration of bonding process.

GOOD SURFACE PREPARATION IS ESSENTIAL TO OBTAIN A METALLURGICALLY SOUND BOND AT LOW PRESSURE SO THAT DISTORTION OF THE DESIRED DEFECT SHAPE IS AVOIDED.
THE FLOW STRESS DATA SHOWN IN THE PREVIOUS PLOT ARE USED TO CALCULATE BOND PARAMETERS.

ANALYTICAL SOLUTIONS TO METAL FLOW PROBLEMS
DIFFUSION BONDING THEORY



ELEVATED TEMPERATURE FLOW STRESS DATA ARE USED TO DETERMINE DIFFUSION BOND PARAMETERS.

(a) SHOWS A PLOT OF FLOW STRESS VERSUS STRAIN RATE.

(b) SHOWS A PLOT OF "m" VALUE OR STRAIN RATE SENSITIVITY VERSUS STRAIN RATE.

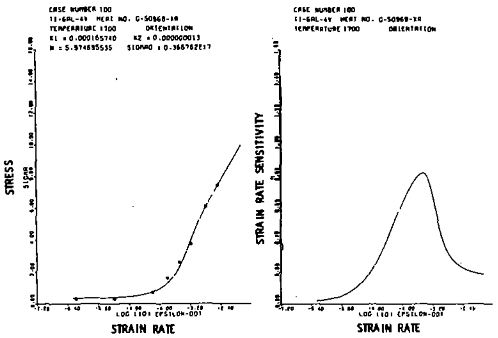
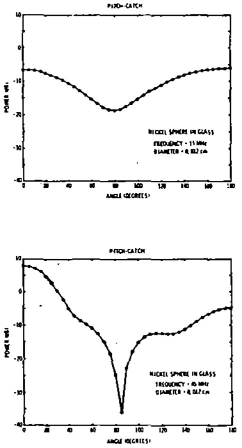


Figure 5. Sample requirements in the diffusion bonding process.

ADVANTAGES

- LOW COST
- LOW ATTENUATION
- LOW CERAMIC NOISE
- OPTICAL TRANSPARENCY
- DURABILITY
- HOMOGENEITY ISOTROPY
- STABILITY (NO DISLOCATIONS)
- REPRODUCIBILITY
- LIGHT WEIGHT (PORTABILITY)



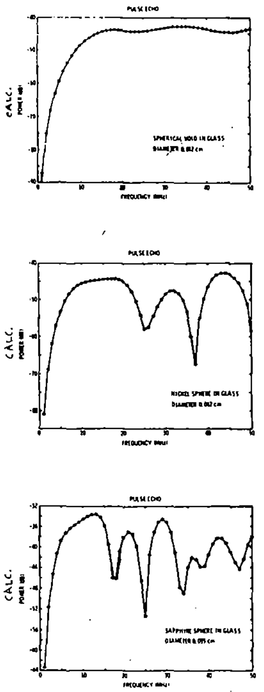


Figure 6. Measurements made on ceramic standards.

DEFINITIONS

CALIBRATION STANDARD

- ULTRASONIC STANDARD SOLELY EMPLOYED TO ENSURE EQUIPMENT IS FUNCTIONING ACCORDING TO SPECIFICATIONS.

REFERENCE STANDARD

- LIBRARY OF SCATTERERS OF DIFFERENT SHAPES USED TO AID IN IDENTIFICATION OF AN UNKNOWN DEFECT AFTER ULTRASONIC SYSTEM HAS BEEN CALIBRATED.

OBJECTIVES

- DEVELOP AN OVERALL SYSTEM CALIBRATION
- DEVELOP A TECHNIQUE THAT HAS SUFFICIENT DYNAMIC RANGE SO THAT LINEARITY CHECK IS MEANINGFUL WITH NO DEGREES OF FREEDOM
- DEVELOP A TECHNIQUE SO THAT SYSTEM CAN BE CALIBRATED AND COMPARED TO THEORETICALLY KNOWN EXPECTATIONS

NEW FEATURE: ULTRASONIC RANGE EQUATION

- ENCOURAGES SEPARATION OF TRANSDUCER EFFECTS, MATERIAL RELIABILITY EFFECTS, PROPAGATION LOSSES AND SCATTERING FROM STANDARD DEFECT.
- INTRODUCES CONCEPT OF "SELF-CONSISTENT CALIBRATION," (i.e. THE USE OF AN ADDITIONAL INDEPENDENTLY DETERMINED, INVARIANT PARAMETER AGAINST WHICH A SYSTEM CAN BE CALIBRATED.)
- SUGGESTS NEW PROCEDURES AND MATERIALS FOR FABRICATING ESSENTIALLY MATERIAL INDEPENDENT CALIBRATION STANDARDS
- INTRODUCES CONCEPT OF TRANSDUCER G-FACTOR AS FIGURE-OF-MERIT IN ANALOGY TO ANTENNA GAIN IN RADAR.
- PERMITS USE OF THEORY AS AID IN FABRICATION, AID IN "PRIMARY STANDARD" CALIBRATION, AID IN DEVELOPING SOFTWARE FOR RAPID, INEXPENSIVE FIELD CALIBRATION.

Figure 7. Results