INTRODUCTION

In recent years, the process of diffusion bonding has found considerable usage in the aerospace and nuclear power industries[1]. This process entails two surfaces being pressed together at elevated temperatures and high pressures. If ideal conditions are achieved, the bonded interface will have properties identical to those of the matrix metal and the microstructure will be continuous across the interface. There is a fine margin for error in attaining ideal conditions and the ability to characterize the bond nondestructively is highly desirable. The present project is aimed at the development of ultrasonic techniques for the characterization of interfaces between two joined parts. The techniques that are being used have applicability to components joined by diffusion bonding, pinch welding, and friction bonding, and may also be useful in nondestructive measurements of rubbing friction and for bond strength.

BACKGROUND

Recent experimental results have shown that ultrasonic reflectivity or transmissivity can be used to explore details of the interface between two joined materials. In one application [2], such measurements have been used to determine the radial component of stress in a shrink-fit coupler; in other applications, related techniques have been shown to be useful in characterizing the state of closure of a fatigue crack [3] and the weld quality in a pinch-welded tube [4]. Theoretical models have also been developed that explain the observed results [5,6]. Both models attribute the behavior of the reflectivity at the interface to asperities contact between the surfaces. Thus, the surfaces are not considered ideally smooth, but are, in fact, held apart on a microscale by the asperities present. As the contacting stresses are increased, the asperities undergo plastic deformation and increase the area of contact thereby decreasing the magnitude of the reflectivity. Application of current models to the experimental results [7] typically yield values of a "spring constant" of the interface or, equivalently, the value of the compressive stress at the interface assuming that the surface roughness and yield properties of the base material are known.
EXPERIMENTAL PROCEDURE

The samples for the present experiments were copper disks of one inch diameter and one-half inch thickness. These disks were annealed at 400°C for one hour and then mechanically polished through Linde B to achieve the desired surfaces. Surface roughness and flatness were analyzed using a Sloan-Dektak surface profile tester. The samples were then bonded at a temperature of 350°C and a pressure of 1500 psi for four hours after removal of surface oxides by heating at 350°C for one hour under flowing hydrogen.

The extent of the bond at the interface was determined from ultrasonic reflection from the interface in the pulse-echo mode. Scans along the sample diameter were taken at 30° rotation intervals in order to obtain a complete picture of the interface. The normalized reflection coefficients were then transformed into contour maps that showed the quality of bonding across the interface.

Metallographic techniques were used on the samples to observe the extent of grain growth across the interface (if any). These techniques will be used also in future experiments to assist in determining grain size effects on ultrasonic scattering.

RESULTS

After annealing and polishing, the samples were tested for flatness, \( \lambda \), and surface roughness, \( H \) as shown in Fig. 1. Data are presented in Table 1, along with other bonding parameters.

![Fig. 1. Schematic of sample surface showing long- and short-wavelength asperity height and wavelengths.](image-url)
Table 1. Bonding parameters.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Side</th>
<th>ASTM Grain Size</th>
<th>$H_1(\mu)$</th>
<th>$H_2(\mu)$</th>
<th>$\lambda_1(\mu)$</th>
<th>$\lambda_2(\mu)$</th>
<th>Bonding Time (h)</th>
<th>Bonding Temp. ($^\circ$C)</th>
<th>Bonding Press. (ksi)</th>
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<tbody>
<tr>
<td>DDP113</td>
<td>A</td>
<td>3</td>
<td>26.0</td>
<td>$\sim$0</td>
<td>1384</td>
<td>$\sim$0</td>
<td>4.0</td>
<td>350</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3</td>
<td>21.8</td>
<td>$\sim$0</td>
<td>1155</td>
<td>$\sim$0</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DDP115</td>
<td>A</td>
<td>5</td>
<td>79.7</td>
<td>$\sim$0</td>
<td>1616</td>
<td>$\sim$0</td>
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<tr>
<td></td>
<td>B</td>
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<td>37.2</td>
<td>$\sim$0</td>
<td>1501</td>
<td>$\sim$0</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

$H_1$ - Average Long-Wavelength Asperity Height  
$H_2$ - Average Short-Wavelength Asperity Height  
$\lambda_1$ - Average Long-Wavelength Asperity Wavelength  
$\lambda_2$ - Average Short-Wavelength Asperity Wavelength  
$\mu$ - micron

Sample DDP113 consisted of two halves with similar grain sizes. Figure 2 is a micrograph of a cross-section of the bond between these halves. Notice that there is very little, if any, grain growth across the interface. However, the bonding is good since a reflection scan from the interface shows that there is little if any reflection over much of the surface (see Fig. 3). The high reflection coefficients at the outer edge of the sample are due to the lack of optical flatness across the sample. The polishing technique during sample preparation creates a cup-shaped profile on the sample, with the outside edge thinner than the center, and results in an unbonded area at the outer edge.

**Fig. 2.** Photomicrograph of diffusion bonded sample showing almost total lack of grain growth across interface (200x).
Contour maps at frequencies of 4 MHz (Fig. 3) and 10 MHz (Fig. 4) were constructed to map the entire interface. Notice that these maps are similar in shape, yet the 10 MHz yields more detailed information on the bond. This, however, was to be expected, as the shorter wavelengths at higher frequencies lead to better resolution and more detailed information for characterization of the interface.

Sample DDP115 consisted of two differing grain sizes. Side A had small grains (ASTM #5) compared to Side B, which was composed of somewhat larger grains (ASTM #3). Micrographs of these grain structures are shown in Figs. 5 and 6.

Reflection scans were taken with the beam incident from both sides. As a result, contour maps were made from both scans using a frequency of 10 MHz (Fig. 7). The two appear similar in nature, but points on the smaller grain side consistently yielded higher reflection amplitudes than the corresponding points on the large grain side. It would seem that more energy was lost in the large grain half than in the small grain half, probably due to scattering.

Figure 8 shows interface reflections at corresponding points on the interface. This plot corroborates the data presented by the contour maps in that the reflection amplitudes are higher for the smaller grain half than those of the larger grain half. One should note that the reflection amplitude drops off faster for the larger grain half at higher frequencies. At lower frequencies, however, the results are fairly consistent. This occurrence can be explained simply by attenuation effects that affect differing microstructures. Backscattered noise experiments to determine grain effects are underway and only initial results have been accumulated.

Fig. 3. Interface reflection coefficient map at 4 MHz of sample DDP113.
Fig. 4. Interface reflection coefficient map at 10 MHz of sample DDP113.

Fig. 5. Photomicrograph of small grain (ASTM #5) half prior to bonding (200x).
Fig. 6. Photomicrograph of large grain (ASTM #3) half prior to bonding (200x).

Fig. 7. Interface reflection coefficient maps from large grain (left) and small grain (right) sides of sample DDP115.
Fig. 8. Interface reflection amplitudes vs. position for corresponding scans on each side of sample DDP115.

FUTURE WORK

A variety of microstructure types will be evaluated to determine the effect of the grain noise on the ultrasonic response of the joined samples. The additional samples to be prepared will cover a wide variation of microstructural details.

The presence of flaws at the interface and their effect on bond quality will also be examined. Investigations will focus both on the detection of flaws at the interface as well as characterization of flaw type and distribution.

Definition of an appropriate destructive test to quantify bond strength will be accomplished in order to obtain a measurable material property to compare against the ultrasonic response of the samples prepared.

ACKNOWLEDGEMENT

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REFERENCES


7. O. Buck, D. K. Rehbein, and R. B. Thompson, to be published.