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ULTRASONIC MEASUREMENTS OF RESIDUAL STRESS

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The use of a material in any mechanical construction requires an estimate to be made of the stress that the material will have to withstand (S_E). Care has to be taken to ensure that the component is designed so that the sum of its breaking stress and the residual stress in the material are much less than S_E. An estimate of the residual stress in a material can be obtained by a strain gauge technique (1). This approach is not particularly reliable and in all cases generous allowances are made for the possible residual stress in components.

It has been indicated by Smallman (1) that ultrasonic shear wave birefringence could be used to measure residual stress but his measurements were hindered by the presence of birefringence due to textural effects in the steel samples he was studying. Mahadevan (2) reports that measurements of ultrasonic shear wave birefringence as a function of frequency allow the separation of the textural effects from the inherent residual stress. We have extended the work of Mahadevan by increasing the frequency range of the ultrasound and by investigating stainless steel, chrome molybdenum steel and aluminium alloys of commercial interest as well as mild steel and glass samples.

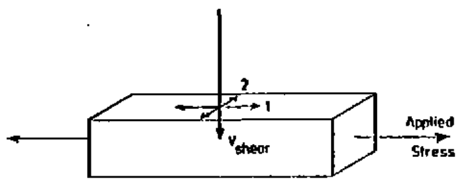

Fig 1 Shear wave polarized parallel (1) and perpendicular (2) to the applied stress

In an isotropic bar of material the velocity of ultrasonic shear waves will be independent of the orientation of the direction of shear wave polarization. If, however, an extensive stress is applied along the length of the bar (Fig. 1) then the velocity of the shear wave polarized parallel to the applied stress will be, in general, less than the velocity of the orthogonally polarized shear wave. The amount of this birefringence is thought to be proportional to the applied stress. Unfortunately in most commercial materials the method of production leads to grain growth that is anisotropic producing a second source of birefringence. Mahadevan reported that the textural contribution was proportional to the frequency of the ultrasound while the portion dependent on residual stress was frequency independent. Separation of the two components was therefore possible, theoretically, by studying the frequency dependence of birefringence from 0.5 - 10MHz. Measurements below 0.5MHz are very difficult because of the comparability of ultrasonic wavelength and transducer diameter while frequencies higher than 10MHz are impossible in steel due to its high ultrasonic attenuation.

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To measure the birefringence as a function of frequency, a pulse echo overlap system was used in conjunction with a single rotatable wide bandwidth shear transducer. By using one or two transducers to cover the frequency range of 1 to 10MHz, bond errors were reduced. It was found that at frequencies above 2MHz, the experimental results tended to be much less scattered and therefore more reliable. This was partly due to the sensitivity of the PEO system decreasing as the frequency decreased. In addition, however, pulse distortion at low frequencies was also evident as the transducer was rotated. The pulse distortion was reproducible and contributed to the velocity differences between the different directions in addition to stress and texture effects. At higher frequencies, where the ultrasonic pulses tended to be more monochromatic, pulse shape tended to be constant as a function of angle.

The samples were approximately 27mm square cross-section by 200mm long and threaded at each end so that tensile and compressive loads could be applied. The transducer diameter was 25mm allowing low frequency measurements to be obtained in the near field, hence minimising diffraction effects. A viscous fluid was used as a coupling agent between the transducer and specimen to ensure that relaxation of the bond after moving the transducer had minimal effects on the velocity. Measurements were made for each stress level at 5^{o} intervals around 360^{o}. However, we only present here the two orientations with shear wave polarisation parallel to the applied stress and the two orientations perpendicular to the applied stress.

Aluminium was chosen as one of the specimens because it has a high stress acoustic constant and so would provide a more sensitive check as to whether birefringence due to texture was frequency dependent.

Figure 2 shows a typical high frequency plot of velocity as a function of tensile load for an aluminium bar. The steeper negative slope is where the particle motion of the shear wave is parallel to the applied stress whereas the shallower positive slope is with the particle motion perpendicular to the applied stress. This apparent increase in velocity is due to changes in sample size as loads are applied. The rolling direction of the aluminium bar is parallel to the applied stress. Figure 2 is typical of all the results for aluminium between 2 and 8MHz. No detectable increase in difference velocity at zero stress was observed in this frequency region (see Fig. 3).

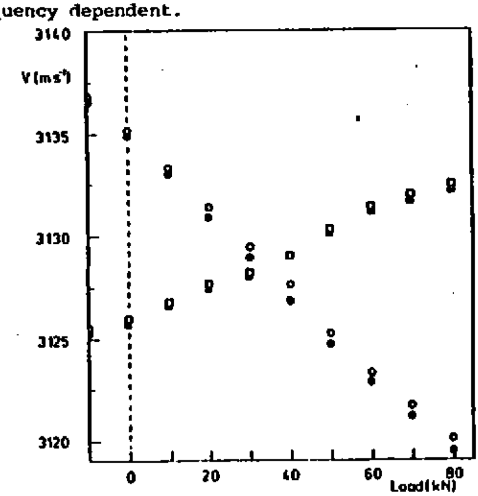

Fig. 2 Stress dependence of velocity of 7.5 MHz shear waves in Al.

○ ● Polarization parallel to applied stress
□ ■ Polarization perpendicular to applied stress

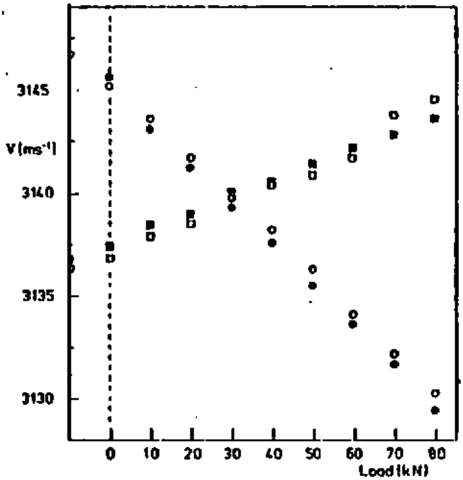

Fig.3 Stress dependence of velocity of 2.2MHz shear waves in Al (Symbols as Fig 2)

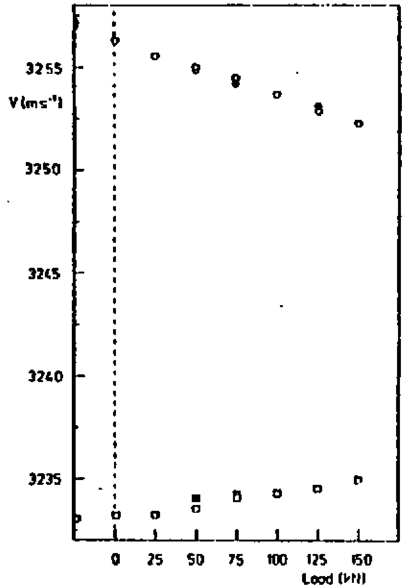

Fig 4 Stress dependence of velocity of 15MHz shear waves in mild steel (Symbols as Fig 2)

Below 2MHz, however, the difference velocity is smallest at zero stress. The gradients are similar to the higher frequency results although more scatter can be seen. This is possibly due to the errors caused by pulse distortion.

In Fig. 4 the results are shown for drawn mild steel bar at 2.2MHz. Again the steeper negative slope is where particle motion is parallel to the applied stress. The gradients are not as steep in mild steel because the stress acoustic constant is smaller than in aluminium. The high value in difference velocity will be due to texture since this sample was annealed and so no residual stress effects should occur. The biggest difference velocity was observed at low frequency, but this may have been a pulse distortion effect rather than a true velocity difference. Certainly, as the frequency was increased to 8MHz no observable increase in difference

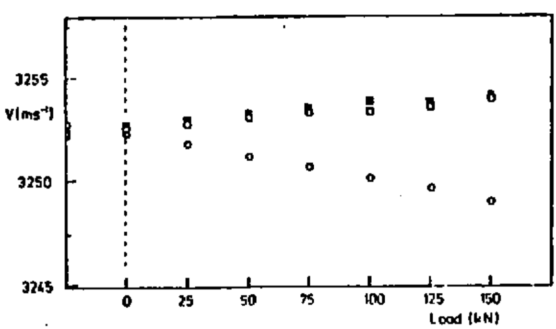

Fig.5 Stress dependence of velocity of 7.5MHz shear waves in CMV steel (Symbols as Fig 2)

velocity could be seen.

Figure 5 shows the results obtained for a Chrome Molybdenum Vanadium (CMV) low creep steel at 7.5MHz. At zero stress no birefringence can be observed within the experimental error of the system. Again the shallowness of the curves indicates a low value for the stress acoustic constant. All CMV specimens tested consistently showed an apparently high difference velocity at low frequencies, together with large differences in velocity in the four directions. This was associated with marked pulse shape changes as the transducer was rotated and so the high velocity differences may, in part, be due to these causes.

Finally, a graph (Fig. 6) is shown for the results obtained with type 316 stainless steel The stress was applied parallel to the rolling direction. The striking feature is that the velocity decreases irrespective of particle motion - whether it is parallel or perpendicular to the applied stress.

It is noticable that we did not find any marked frequency dependence of velocity differences in the unstressed state of any of the materials. Also, a linear relationship between time of flight differences and frequency has not been found, indicating the need for further work to attempt to separate the texture and stress effects on birefringence.

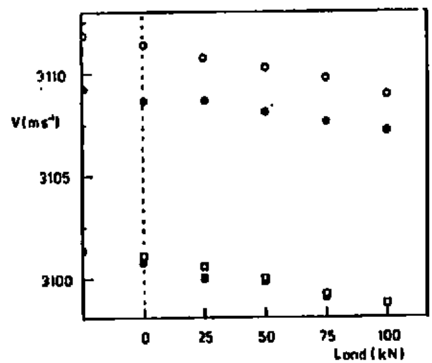

Fig.6 Stress dependence of velocity of 7.5MHz shear waves in stainless steel (Symbols as Fig.2)

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