

Load Cell Ringing in High Rate Compression Tests

Mechanical test machines play an important role in providing simulation data to underpin careful analysis of high rate processes. In many cases elements of the test frame or testpiece can vibrate when subjected to a high rate force. The transducers attached to the machine frequently register this vibration superimposed on the true signal and thus may mask the signal required for analysis.

At impact all the parts of the test machine oscillate at their natural frequency (dependent on stiffness and mass). Ringing in test machines is determined by

- rate at which the testpiece is deformed
- elastic characteristics of test material
- resonances in components of load train anvils in compression.

In the current work high rate hot compression tests are being developed to provide best practice measurement guides on test methods for studying the dependence of strength on deformation rate and temperature. At higher rates of deformation ringing is observed in the transducer signals for load and displacement and this measurement note summarises the results of systematic tests to investigate this issue. A purpose built software tool was developed for analysing the time dependence of the transducer signals and this is described in the Measurement Note.

B Roebuck, M Brooks and M G Gee

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INTRODUCTION

Material properties are strain rate sensitive and thus it is important to have measurement methods that are accurate and appropriate. Numerical simulation and physical models used to control and evaluate industrial processes increasingly require data of higher precision. This is particularly difficult when events occur at high rates of change.

A wide range of industries require an understanding of both manufacturing routes and performance analysis where high rate processes have a significant impact on the product outcome. These can include:

- High rate deformation processes, such as extrusion, rolling and forging
- Impact phenomena in transportation.

High rate impact events can easily apply strain rates of 100 s^{-1} with millisecond duration.

In some circumstances, i.e. testing at room temperature, it can be useful to fix a strain gauge to the thicker grip section of the testpiece, thus enabling the specimen to act as a miniature load cell and minimise the distance and mass between the gauge section of the testpiece and the wider section where the strain gauge is attached.

In other tests, data can be filtered to remove or reduce the ringing effects, either as it is collected or post-test. Ringing analysis is good for removing the frequency components but care is needed in evaluating the initial elastic response and proportional limit (yield point).

NPL, working in a consortium with the Universities of Wales (Swansea) and Sheffield, has been investigating this effect in hot high rate compression tests.

At NPL the ringing characteristics of two test systems has been evaluated. In one of the test systems a servohydraulic frame is used to impose a constant velocity crosshead control test and in the other system a cam plastometer is used to apply a constant strain rate test.

Tests were conducted on four materials at a range of strain rates and temperatures

- Al alloy 5052; 300-500 °C
- 316 stainless steel; 1050-1150 °C
- Nimonic 901; 950-1050 °C
- Eutectoid steel; 1000-1100 °C

Nominal strain rates
 $0.1\text{-}200 \text{ s}^{-1}$

Figure 1 shows nominal stress/time curves from the cam plastometer test system for Al alloy materials.

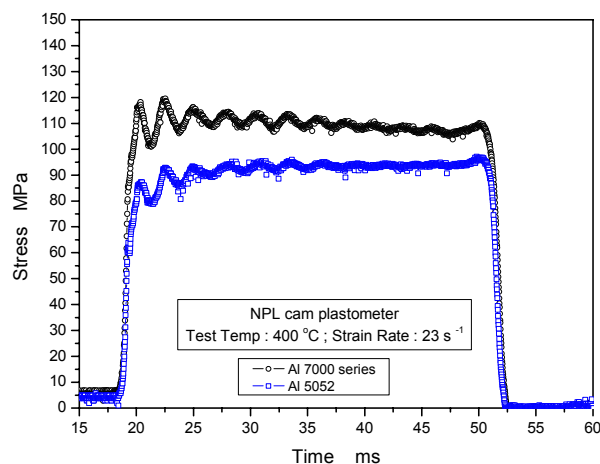


Fig 1 Nominal stress/time curve at 23 s^{-1} (cam plastometer) showing ringing effect in test on Al alloys.

RINGING ANALYSIS

LABVIEW SOFTWARE

An output from the consortium has been an interactive software programme that can be used to investigate the transducer signals.

The approach assumes a damped sinusoidal frequency response appropriate to a spring-mass system with an exponential decay, i.e.

$$A = P \exp(Bt) \{R \sin 2\pi f(t + \varepsilon)\}$$

where P, R and B are amplitude and decay constants, ε is a phase shift parameter, t is time and A is the signal amplitude.

The NPL analysis system used Labview® software to provide a framework for the following algorithm for analysing the load/displacement v time data obtained from the test system:

- Fit a smoothed curve to the data, using either running average, polynomial or step wise functions
- Subtract smoothed curve from measured data

- Conduct frequency analysis (Fourier transform)
- Fit amplitude decay (assumed exponential)
- Subtract functional reconstruction from original data
- Plot corrected curve.

Other curves can be fitted by interaction with the Labview programme. This has been constructed to be user friendly with trial selection, if necessary, of fitting parameters.

An example of the front panel of the analysis system is shown in Fig 2 illustrating the extracted ringing curve, the analytical fit and a Fourier analysis of the relevant peaks.

Another schematic graph is shown in Fig 3 with the decaying sinusoidal curve superimposed.

The most important issue remaining to be addressed remains that of rise time in the initial elastic regime. This can be reduced by cutting the mass involved in the system or establishing faster sensor systems. Alternatively selected smoothing of the load signal can be adopted

FRONT PANEL

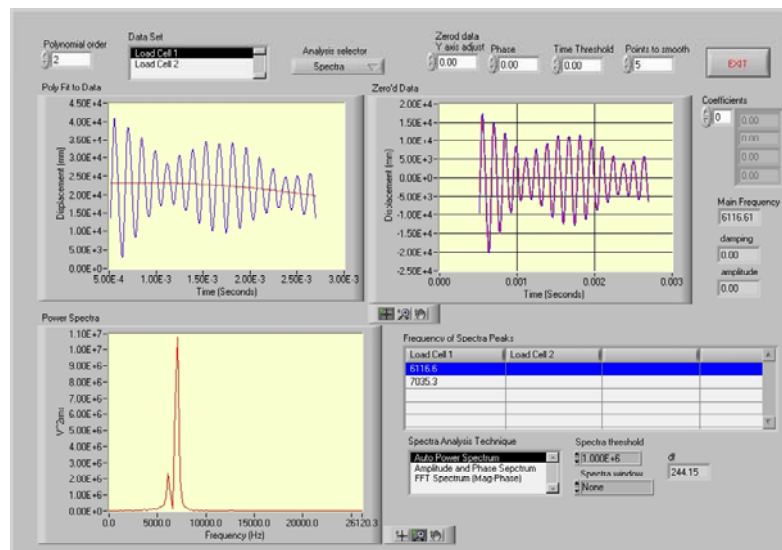


Fig 2 Labview ringing programme front panel.

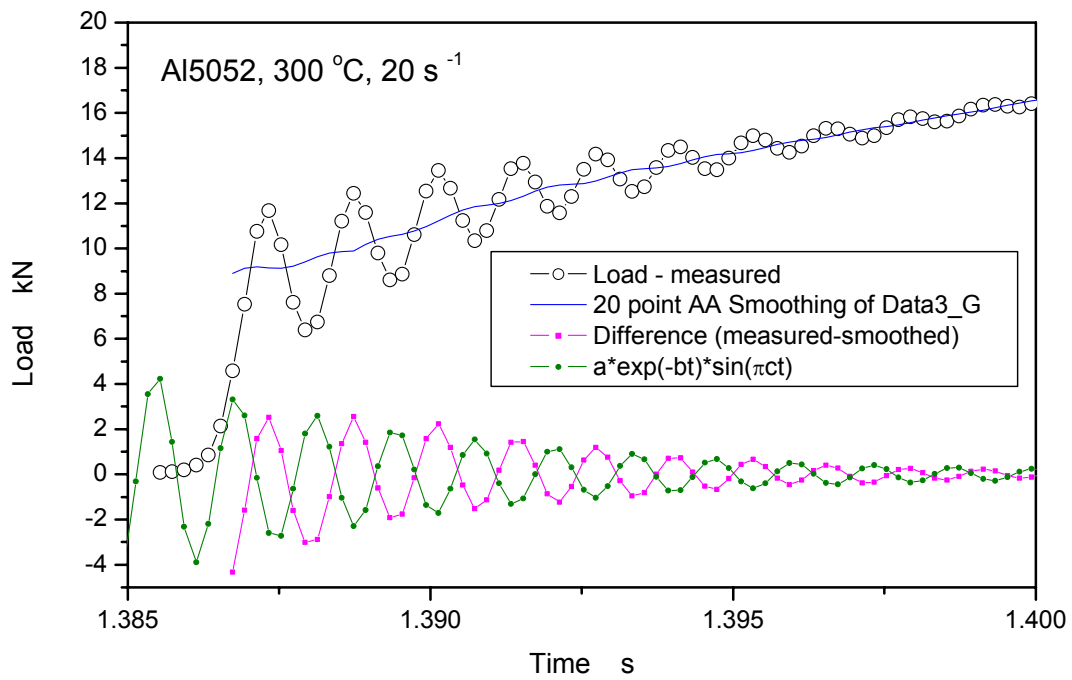


Fig 3 Graph showing characteristics of analytical procedure.

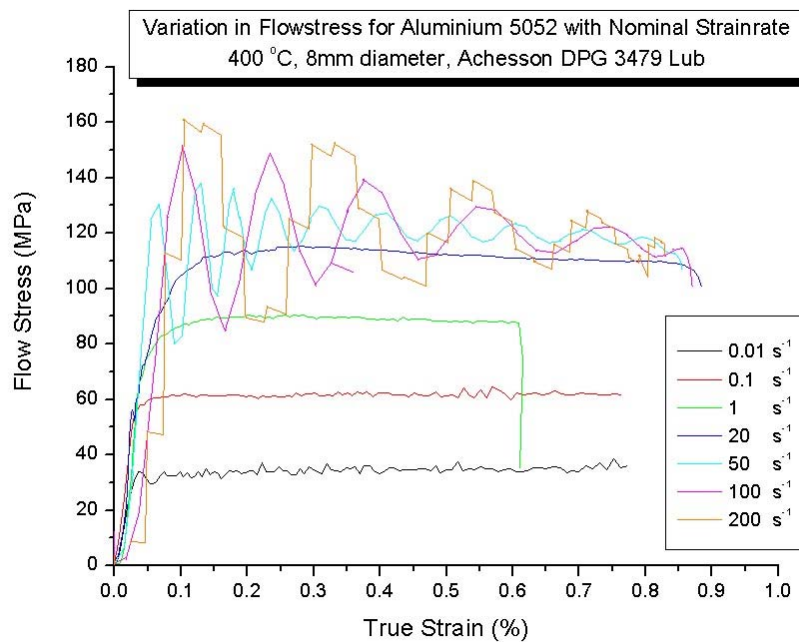


Fig 4 Effect of increasing strain rate on ringing effect in tests on Al alloy 5052 at 400 °C

RINGING EXPERIMENTS

Experiments were performed on four alloys to evaluate the effects of test system, test temperature, strain rate and testpiece size on ringing frequency. The Labview software programme was used to extract this data from the measurement load/time values. A set of stress/strain curves from tests on the Al alloy at 400 °C are shown in Fig 4 for different strain rates from 0.01-200 s⁻¹. It can be seen that the ringing effect is not apparent until high strain rates are obtained (. 20 s⁻¹).

Two testpiece geometries were examined, 8 mm diameter × 12 mm long and 10 mm diameter × 15 mm long in the servohydraulic test system and 4 mm diameter by 6 mm long in the cam plastometer. The ringing frequencies measured from tests using the servohydraulic system are shown in Fig 5 for four materials, Al 5052, 316 stainless steel, Eutectoid steel and Nimonic 901

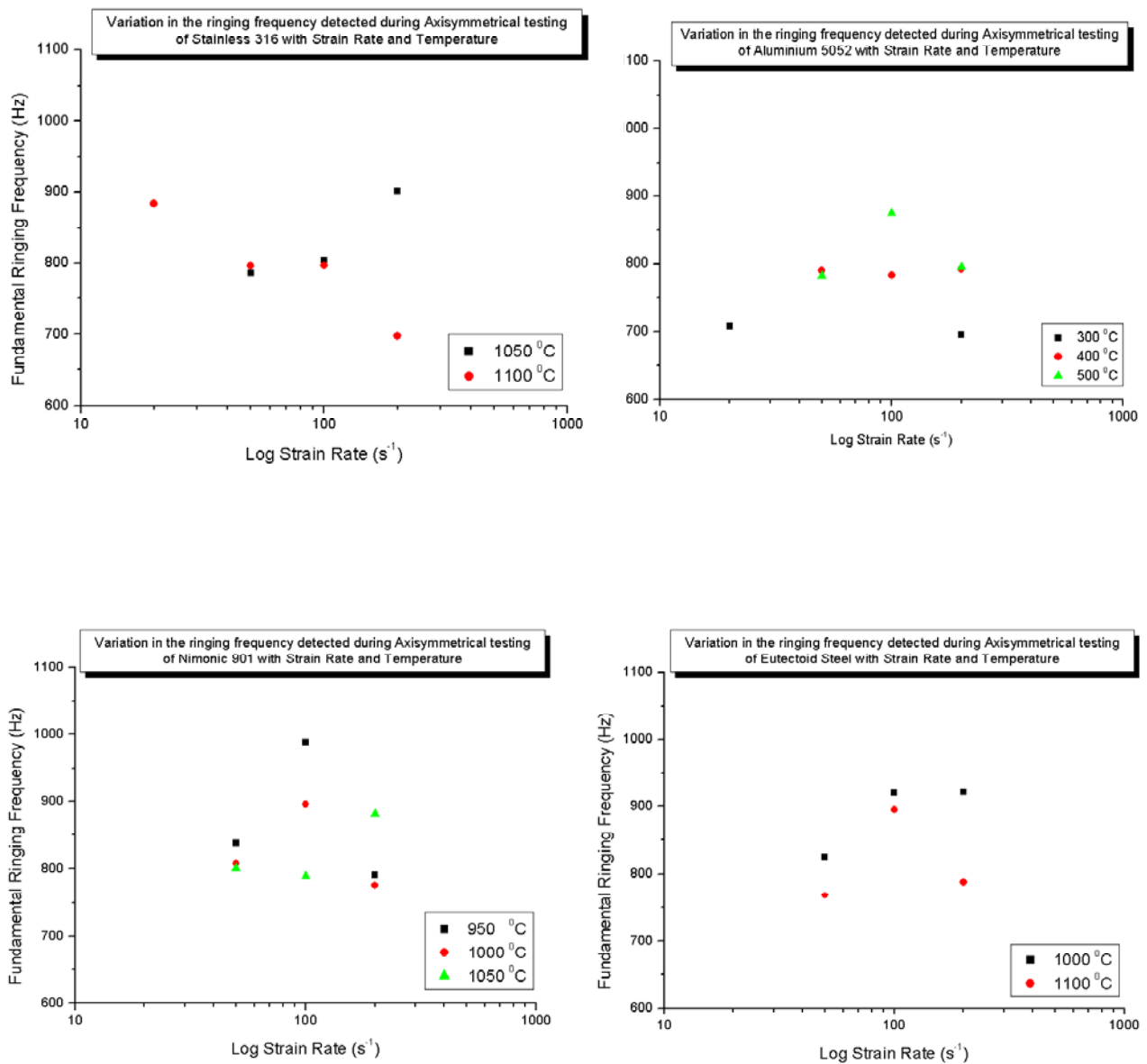


Fig 5 Variation of ringing frequency with temperature and strain rate for four materials.

A comparison of the ringing frequencies for each material at selected strain rates and temperatures is shown in Fig 6. It can be seen that there is little systematic effect of any of these parameters and the system frequency is about 800 Hz. Similar tests in the cam plastometer again found little effect of these parameters but the system frequency was about 600 Hz. A piezoelectric load cell was used in the cam plastometer whereas the load cell in the servohydraulic system was a conventional strain gauged device. However, amplitude is affected by deformation parameters as can be seen in Fig 7 which shows increasing amplitude with increasing strain rate.

Experiments were also performed to examine the effect of anvil type. These experiments were conducted in the cam plastometer. Four platen materials were examined:

- IN718 (Ni alloy)
- CMSX4 (Ni single crystal)
- MARM204 (Ni alloy)
- Sialon (Ceramic)

Tests were conducted on two testpiece materials, Al 5052 and 316 stainless steel, at three strain rates (23, 90 and 135 s⁻¹) at room temperature. The Labview software was used to analyse the load/time and displacement/time plots for ringing frequency and the results are shown in Fig 8 where the ringing frequencies are plotted against the stiffness (Young's Modulus) of the anvil. The results show that there was little effect of all these parameters and a frequency of about 600-700 Hz was measured. This was similar to that found in high temperature tests using the cam plastometer.

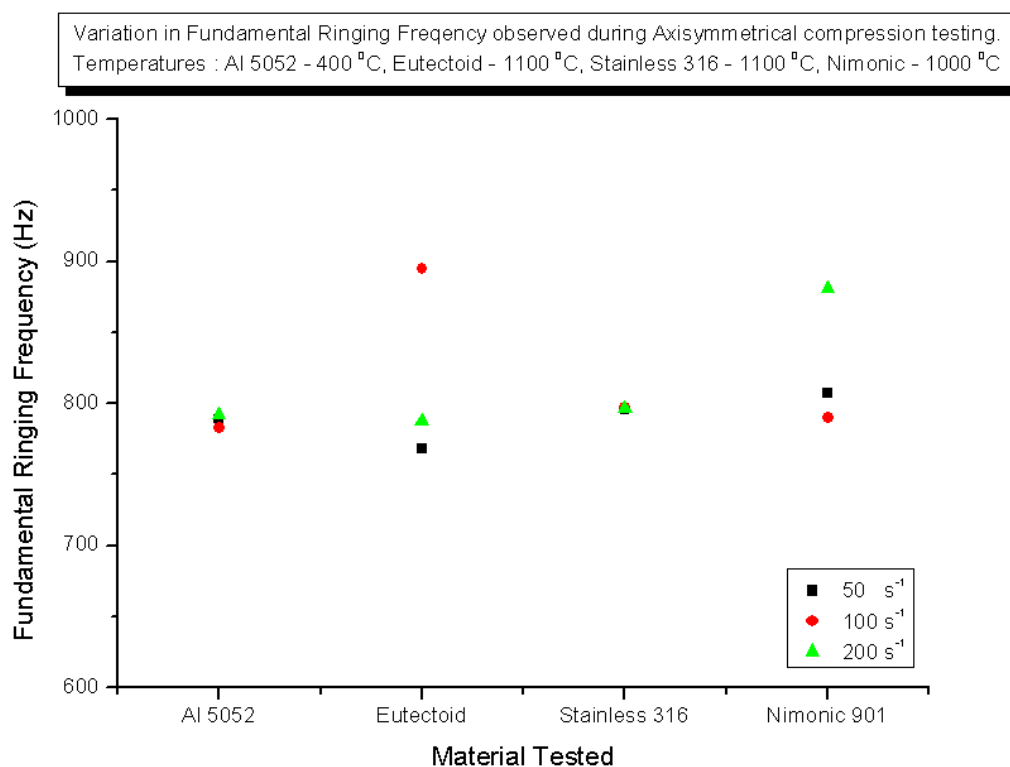


Fig 6 Comparison of ringing frequencies for each material.

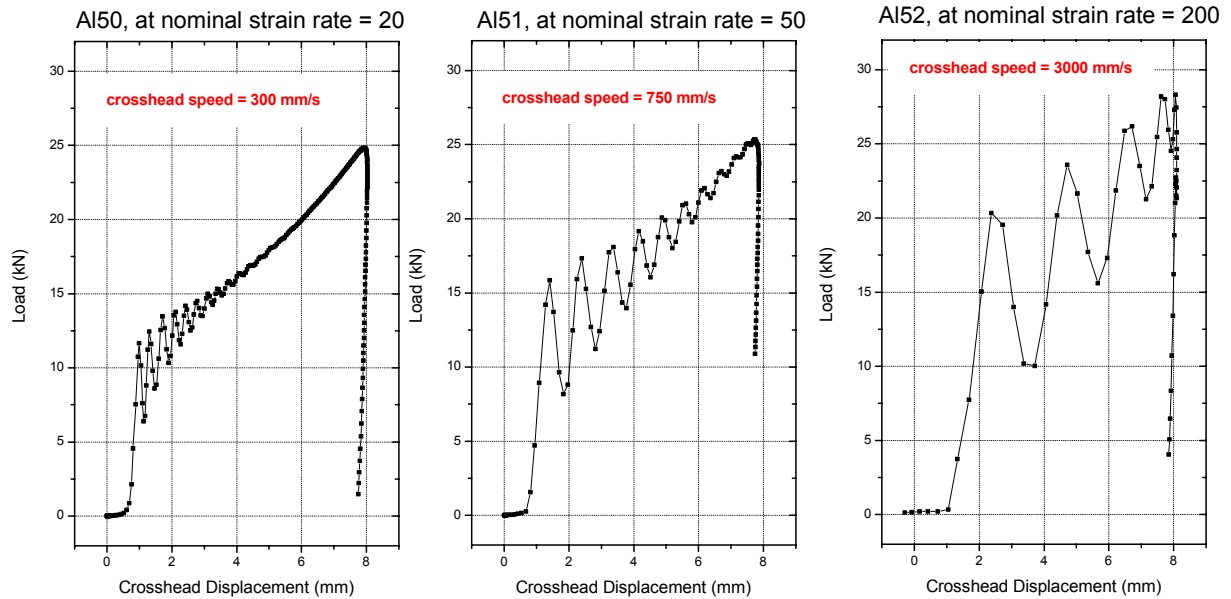


Fig 7 Effect of increasing strain rate on magnitude of ringing effect in tests on Al alloy 5052 at 400 °C

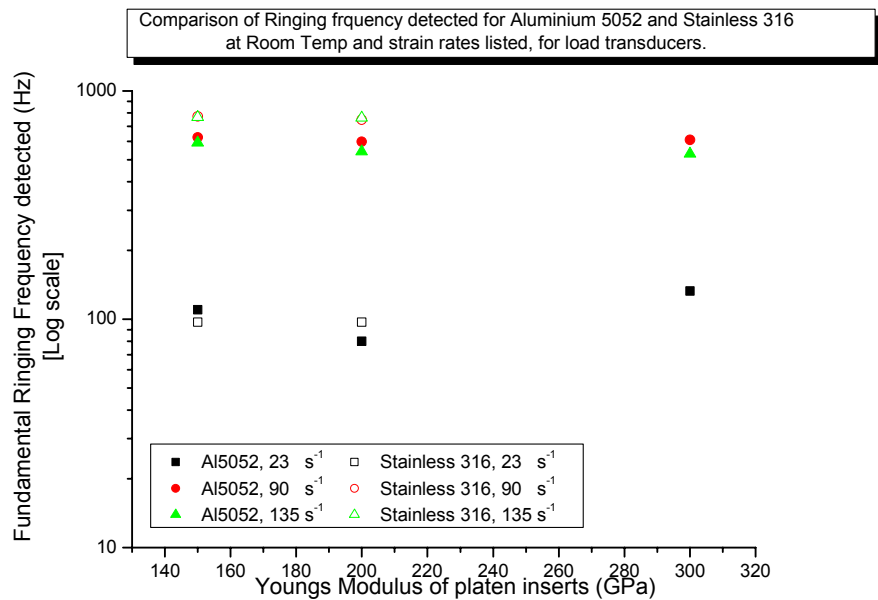


Fig 8 Effect of anvil type on ringing frequency in tests on Al 5052 and 316 Stainless Steel at room temperature.

SUMMARY

The phenomenon of ringing has been explored in high rate hot compression tests using a number of test systems. It has been shown that in most of the systems the ringing signal is seen to be a damped sinusoidal frequency response appropriate to a spring-mass system with an exponential decay.

It was shown that in at least two significantly different systems that the ringing frequency was independent of:

- Material type
- strain rate
- test temperature
- anvil type

but that all these parameters could affect the signal amplitude and decay. A software system was developed to extract the ringing decay curve from the measured signal in order to reveal the underlying load/displacement signal from which a corrected stress/strain curve can be calculated.

ACKNOWLEDGEMENTS

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FOR FURTHER INFORMATION CONTACT

Dr B Roebuck
Materials Centre
National Physical Laboratory
Queens Road
Teddington, Middlesex TW11 0LW

Tel: 020 8943 6298
Fax: 020 8943 2989
e-mail: bryan.roebuck@npl.co.uk