DYNAMIC PROPERTIES OF HIGH STRENGTH METALLIC MATERIALS

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The flow stress and fracture toughness of many metallic materials is known to be rate dependent. The general tendency is an increasing tensile strength and flow stress with increased rate of loading. The dynamic stress/strain relationships have been obtained for several metallic materials. The medium strain rate tests (80 s^{-1}) were carried out on a servo-hydraulic single shot machine with a newly developed low-inertia extensometer. The high strain rate of ca. 1000 s^{-1} was achieved with the split Hopkinson Pressure Bar (SHPB) where a compressive stress wave reflected as a tensile wave is used to load threaded tensile specimens.

INTRODUCTION

There is overwhelming evidence of the strain rate sensitivity of the mechanical behaviour of most metals and alloys as well as many composites and non-metallic materials. In many structural impact problems, metal forming and metal cutting processes, the localised loading rate is very high. There continuously greater demand for more efficient and economic use of materials and to ensure safety and reliability, many industries such as the nuclear, pressure vesels, aircraft, ship building and car industries, use complex finite element analysis. These theoretical analyses require realistic material properties input to provide reliable predictions.

A report prepared by Baker (1) for the EEC Bureau of reference emphasised the importance of determining material behaviour under impact loading.

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Experimental results show a significant increase in flow stress with increased strain rate for metallic materials of face centred cubic (fcc) and body centred cubic (bcc) structures. Recent reviews by Nicholas (2) and Harding (3) discussed in detail the various experimental techniques of high strain rate testing and strain rate effect on a wide range of engineering materials. The difficulty of developing a constitutive relationship between stress and strain, strain rate and temperature arising from the effect of strain rate history was highlighted.

In this paper the results of dynamic tensile tesing for medium strain rate (100 s^{-1}) and high strain rate (1000 s^{-1}) are compared with quasi-static strain rate (10^{-3} s^{-1}) test results. The test programme is carried out on a single shot servo-hydraulic closed loop testing machine with a specially developed low inertia clip gauge. The higher strain rate tests are conducted on split Hopkinson pressure bar apparatus. Other techniques used for dynamic strain rate sensitivity investigations are Taylor ballistic test, described by Hashmi (4) and shadow optic photography for drop weight loading and instrumented impact testing, described by Kalthoff (5).

Experimental Technique

A new method is used for the dynamic tensile testing on a servo-hydraulic single shot machine with a specially developed low inertia clip gauge with a suitable method of mounting on the specimen. The details of the technique and its advantages over other common methods such as instrumented impact tension test are described in a paper by Al-Mousawi et al (6). This technique can only be used for strain rates of up to 100 s^{-1}. It has the advantages of being relatively simple and easy to use. It is repeatable and reproducable with the data acquisition and plots fully computerised. These advantages are important for any test method to be considered for wider application in industry and test laboratories as was pointed out by MacGillivray and Cannon (7). The higher rates of up to 1000 s^{-1} are achieved with the use of the split Hopkinson pressure bar (SHPB) apparatus in a special arrangement for tensile impact testing. This setup together with several other possible arrangements are described in a report by Al-Mousawi (8). The SHPB for tensile loading is shown schematically in Figure 1. In this system the input compressive wave due to impact is propagated along the input bar (1) which is twice as long as the second transmitter bar (2). This compressive wave is transmitted almost entirely through a collar placed over a threaded end tensile specimen and firmly fitted against the shoulders of the pressure bars. This compressive pulse is reflected as a tensile pulse from the free end of the transmitter bar. This tensile pulse is used to load the specimen. The SHPB provides a relatively cheap universal method of dynamic testing with an acceptable level of accuracy provided sufficient care is taken with choice of proper instrumentation. The incident, reflected and transmitted strains are measured with strain gauges positioned on each of the two pressure bars. A typical output of these strain gauges is shown in Figure 2.

RESULTS AND DISCUSSION.

A test program was carried out for several metallic materials including titanium alloys, stainless steel, Nickel-Aluminium Bronze and EN 5K steel.

Figure 3 shows the effect of strain rate on the tensile strength of En 5K at room temperature where comparison is made between dynamic and quasi-static stress/strain curves. The tensile specimens used are of cylindrical section of 5 mm diameter and 14 mm gauge length. The quasi-static tensile test was carried out on an Instron Testing machine at a strain rate of 10^{-3} s^{-1}, the medium strain rate dynamic tensile test was carried out on the ESH testing machine at a strain rate of 80 s^{-1} and dynamic tensile test on SHPB apparatus was at a strain rate of 830 s^{-1}.

The strain rate sensitivity of the flow stress at 2, 3, 4 and 5 percent plastic strain is illustrated in Figure 4 in which a significant increase in flow properties occurs at the medium strain rate and a much higher increase at the high strain rate is clearly demonstrated.

These graphs show the general trend of increased tensile strength with increased loading rate, but the exact form of the graphs needs several additional tests at intermediate strain rates where some scatter of experimental data is expected.

CONCLUSIONS

There are few experimental results published on the dynamic stress/strain relationship of strain rate sensitive materials. The effect of loading rate on the ultimate tensile stress (UTS) and the flow stress was investigated for a number of metallic materials, a sample of which was illustrated. The new technique of the low inertia clip gauge, as opposed to direct strain gauges on the specimen, enables the determination of the full dynamic stress/strain curves and strain at failure. A major advantage is the lack of various oscillation which often hindered the derivation of meaningful dynamic stress/strain curves from drop weight tests and instrumented impact testing. The use of the SHPB showed continuous strain rate sensitivity at higher strain rates.

Acknowledgements The author wishes to thank Mr R A Preston for checking the manuscript and Miss T Johnson for her efficient typing of the paper.

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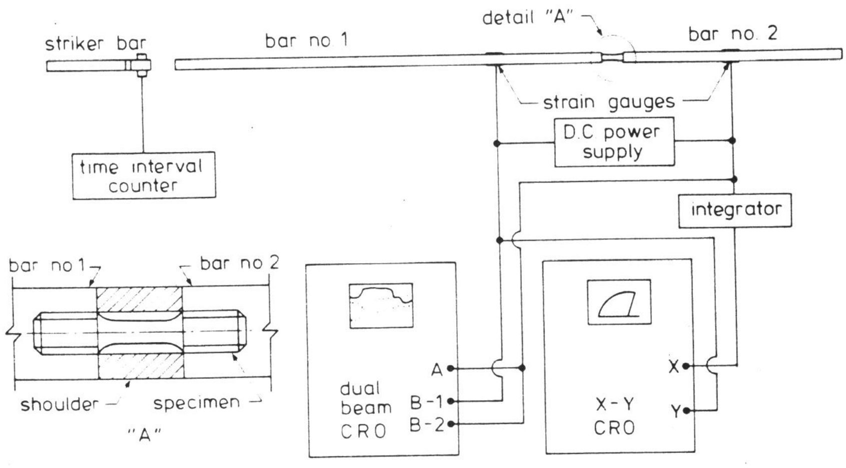

Figure 1: Tensile Test Arrangement of the Split Hopkinson Pressure Bar

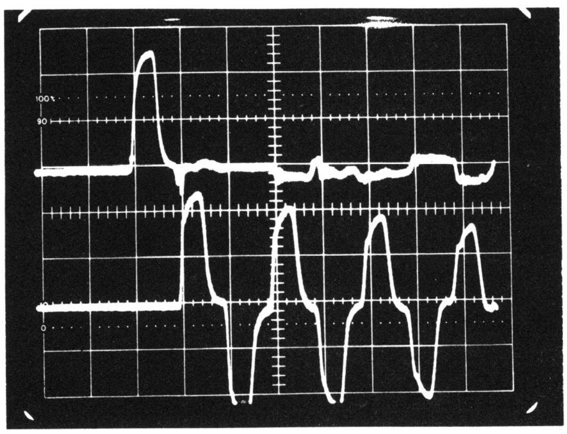

Figure 2: Typical Record of Incident and Reflected Waves

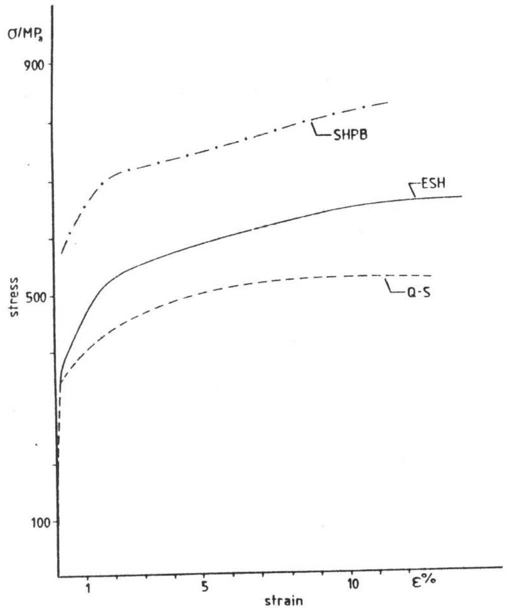

Figure 3: Dynamic and Statics Stress
Strain Curves for En 5K Steel

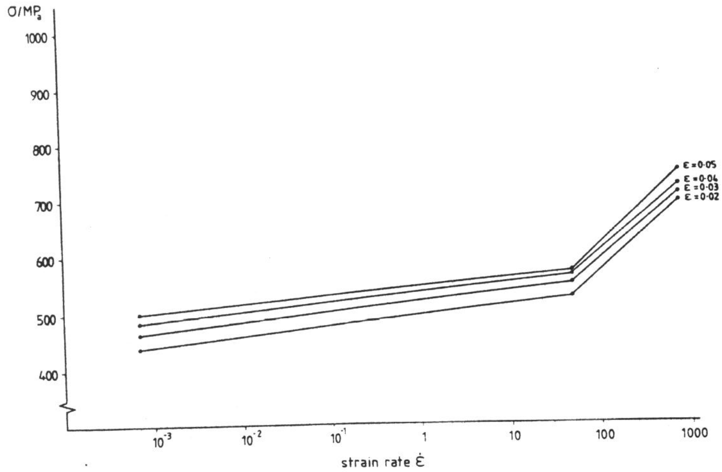

Figure 4: Strain Rate Sensitivity of Flow Stress for En 5K Steel