# THE EFFECT OF STRAIN RATE AND TEMPERATURE ON THE IMPACT BEHAVIOUR OF AUTOMOBILE COATINGS

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The effect of strain rate and temperature on the impact behaviour of three automobile coatings has been assessed in the strain rate range $10^{-4}$ to $10^{4}$ $s^{-1}$ and temperature range -20 to 40 °C. All tests are carried out in compression on specimens manufactured from films of thickness 0.04 mm with the high rate testing being performed on a split Hopkinson pressure bar apparatus. The results, presented in the form of stress strain curves and Eyring plots show the coatings to be highly strain rate sensitive within the range of temperature and strain rates applied. Furthermore, this approach provides an efficient method of determining the combination of strain rate and temperature necessary to cause fracture during impact.

## INTRODUCTION

Manufacturers of automobile coatings are continually searching for more efficient and reliable methods of assessing the impact behaviour of new and existing coatings such that their performance can be improved. The impact behaviour of coatings, mainly their susceptibility to chipping, is normally assessed by qualitative methods most of which involve monitoring the impact and temperature conditions required to puncture the coating, Maier and Liable (1). While such methods are useful as comparative tests in differentiating between the performance of selected coatings, they do not provide information on the mechanical constitutive relationships which govern their behaviour and how these are affected by changes in impact conditions such as velocity and temperature.

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The development of tests methods which would therefore provide this much needed quantitative information about the properties of the coatings has been some what hindered by difficulties in the impact testing of films. In an earlier paper, Dioh and Williams (2) presented a methodology by which the quantitative behaviour of coatings can be assessed in terms of their stress/strain behaviour in the strain rate regime $10^{-4}$ to $10^{4}$ $s^{-1}$. In the method, the high strain rate behaviour is assessed from split Hopkinson pressure bar tests, Lindholm (3), while the low rate tests are carried out in mechanical screw driven and hydraulic testing machines. The problems associated with testing thin films, of typical thickness 0.04 mm, are overcome by employing a technique in which specimens are manufactured by stacking individual films until the appropriate thickness is obtained. An added advantage of this method is that the behaviour of multi-layer systems in which embrittlement may occur can also be studied.

In this paper, experimental results are presented which indicate that this approach can be used successfully to determine the combination of strain rate and temperature necessary to cause fracture of these coatings. In addition, quantitative results in the form of stress strain curves are also presented, making the formulation of constitutive material models possible. Such models can be subsequently used for analytical and/ or numerical analysis of the failure processes which occur during the high rate deformation of these materials. Three automobile coatings for different applications have been studied. For confidentiality these will be referred to simply as A, B and C.

## EXPERIMENTAL PROCEDURE

Only a brief description of the experimental procedure will be presented here as it has been outlined in detail elsewhere; Dioh and Williams (2). All the materials were supplied by Dupont in the form of thin films of thickness 0.04 to 0.07 mm. The samples were stacked and machined into discs of diameter 12.7 mm and thickness 4.4 or 1.0 mm. The 4.4 mm and 1.0 mm thick specimens were used for the low rate and high rate tests respectively as each has been shown to yield accurate results at the respective rates; Dioh et al (4, 5). Briefly, the split Hopkinson pressure bar in its compressive configuration consists of two long elastic bars. Sandwiched between these bars (referred to commonly as the input and output bars) is a disc shaped specimen. Care is needed in placing the specimen between the bars due to the possible misalignment of the individual loose films. Both the input and output bars are made from 15.8 mm diameter high strength aluminium (HE15). The free end of the input bar is subjected to an axial impact by a projectile made from the bar stock. This generates a compressive loading pulse which travels along the input bar towards the specimen. Due to a difference in mechanical impedance between the bars and the specimen, interaction of the incident pulse and the specimen results in stress waves being reflected back into the input bar and also being transmitted through the specimen into the output bar. Having recorded the incident, reflected and transmitted strain pulses at fixed points in the bar the displacement and stress conditions at the specimen-bar interfaces can be established. From these, the stress/strain behaviour of the samples can be obtained at high strain rates.

For the right choice of specimen dimensions, the classical split Hopkinson pressure bar approach as outlined by Lindholm (3) yields fairly accurate representations of the inherent stress strain behaviour of the materials. Otherwise, inaccuracies in the stress strain curves may be obtained, Dioh et al (4). The results from the experiments are presented below. In the present work, an impact velocity in the region of 10 to 18 m $s^{-1}$ is employed in all the high rate tests. A cooling/heating sleeve linked to a temperature controller (± 1.0°C) is used to alter the specimen temperature.

## RESULTS AND DISCUSSION

Typical experimental results obtained are shown in figures 1 to 4. Figure 1 shows stress strain curves at 20°C for coating A in the low, intermediate and high strain rate regimes; $10^{-4}$ to $10^{4}$ $s^{-1}$. The results shown in figure 1 have been obtained for all three coatings at four temperatures in the range -20 to 40°C; -20°C, 0°C, 20°C and 40°C. It is clear from figure 1 that coating A is highly strain rate sensitive and shows a transition from a J-type stress strain behaviour at low rates, in which the modulus increases continuously with strain to a knee-type behaviour at high rates. This transition in the fundamental behaviour of the material is also seen as the test temperature is reduced from 40°C to -20°C. All other coatings studied exhibited similar results, however, the strain rate and temperatures at which the transition takes place is markedly different between coatings.

The strain rate sensitivity of each coating can be better assessed by presenting the experimental data in the form of an Eyring plot. Eyring plots for coatings A, B and C are shown in figures 2, 3 and 4 respectively. In each plot, the 10% flow stress/temperature is plotted against the strain rate. Since the coatings do not exhibit a yield point in compression in the strain rate and temperature range studied, the 10% flow stress is used in the plots instead of the customarily used yield stress. From figures 2, 3 and 4, values of the activation energies for each material can also be obtained if the results at a particular temperature are considered. From figures 2 to 4, it is clear that this method can also be used to determine the combinations of strain rate and temperatures required to cause fracture/chipping of the coating under impact loading. A region can be identified for each coating within which chipping will not be expected for any combination of strain rate and temperatures. Therefore, it is possible (a); to assess the susceptibility to chipping of various coatings as well as obtain quantitative high rate data and (b); to quickly and reliably compare the impact performance of various coatings.

## CONCLUSIONS

The effect of strain rate and temperature on the impact behaviour of three automobile coatings has been assessed in the strain rate range $10^{-4}$ to $10^{4}$ $s^{-1}$ and temperature range -20 to 40 °C. The results show all coatings to be highly strain rate and temperature sensitive within the range of temperature and strain rates applied. In addition, this approach provides an efficient method of determining the combination of strain rate and temperature necessary to cause chipping of the coatings during impact.

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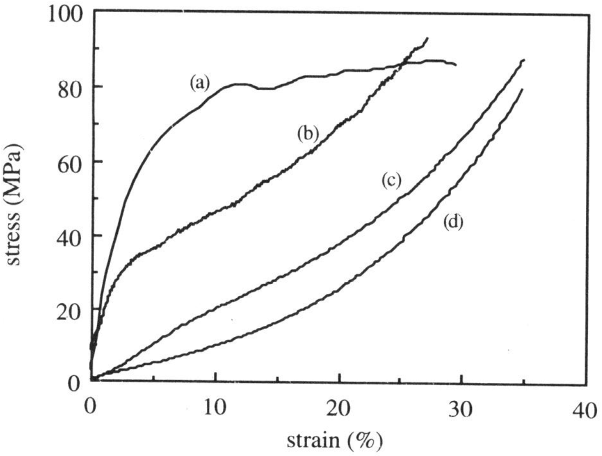

Figure 1 Stress strain curves for coating A at low, intermediate and high strain rates; (a), 4000 $s^{-1}$; (b), 10 $s^{-1}$, (c) 0.8 $s^{-1}$ and (d) 0.008 $s^{-1}$.

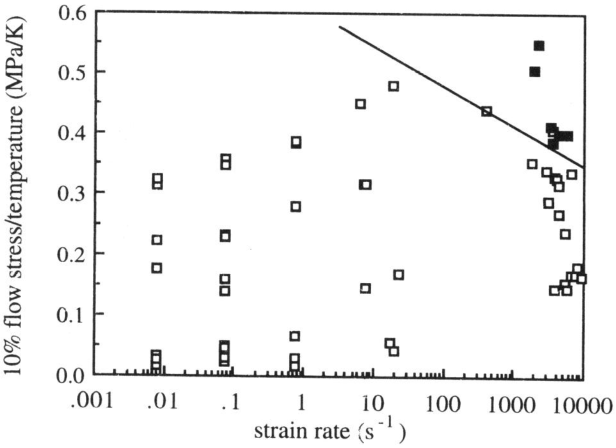

Figure 2 Eyring plot for coating A. Filled squares denote specimen fracture

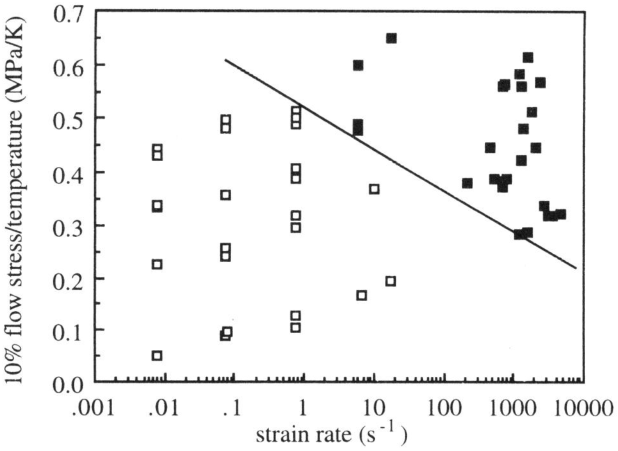

Figure 3 Eyring plot for coating B. Filled squares denote specimen fracture

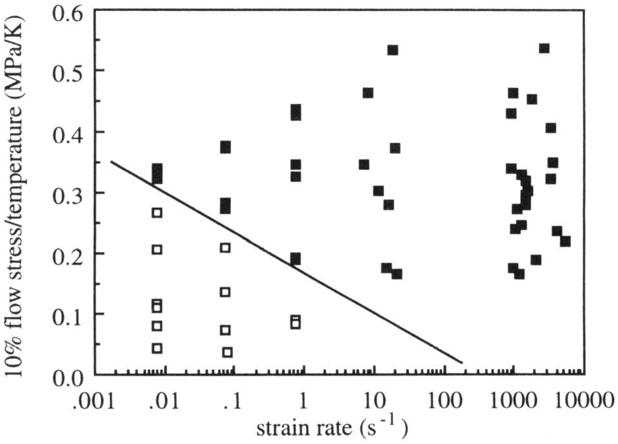

Figure 4 Eyring plot for coating C. Filled squares denote specimen fracture