## Production of Tensile Shock Waves in Stretched Natural Rubber

It may be shown theoretically that when plane mechanical pulses of finite amplitude travel in non-dispersive media, the velocity of propagation in space is given by $c+V$ where $c=(S/\rho)^{1/2}$, $S$ being the tangent modulus of the material and $\rho$ its density, and $V$ is the particle velocity associated with the pulse. If $S$ increases with increasing amplitude of deformation, the head of the pulse will become steeper as it travels through the medium and it will eventually become a shock front, the gradient of which is limited by dissipative processes, such as internal friction and thermal conductivity. Such compressive shock waves are well known in fluids and in recent years similar shock waves have been produced and studied in blocks of solids[1].

It has been suggested[2] that a similar phenomenon might be expected for propagation of finite tensile pulses travelling along bands of highly stretched vulcanized natural rubber, because in this region the material becomes increasingly stiff with increasing tensile strain[3]. Lee and Tupper[4] suggested that a similar effect might occur in mild steel because this material has an S-shaped stress–strain curve. No experimental evidence of the generation of such tensile shock waves seems to have been published, however, although Mason[5] describes evidence of a similar phenomenon for the retraction of stretched rubber, but in this case the pulse must be considered as compressional.

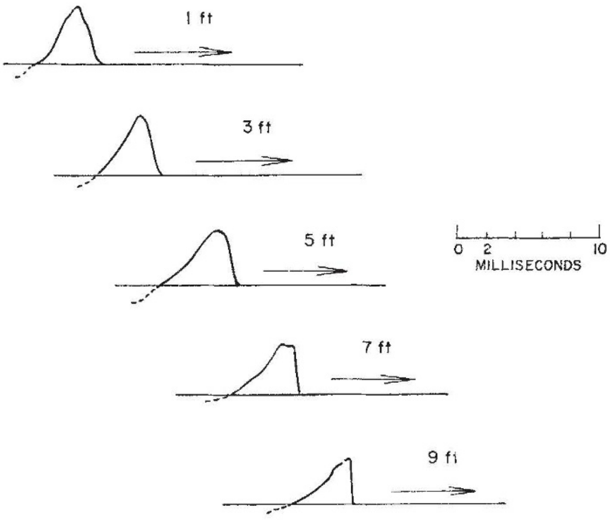


Fig. 1.

Because vulcanized natural rubber exhibits a large attenuation of wave amplitude in the unstretched condition, it was necessary to pre-strain the rubber greatly before any shock wave formation could be observed. A band of vulcanized natural rubber gumstock of square cross-section ($\frac{1}{2}$ inch × $\frac{1}{2}$ inch in the unstretched state) was pre-strained to five times its original length. A 13 foot length was clamped at opposite ends of an optical bench and a section 10 inches long, at one end of the stretched rubber, was then stretched even further. The additional stretch was maintained by a piece of steel piano wire. When this wire was suddenly volatilized by a heavy electric current, a tensile pulse travelled along the stretched rubber, and the velocity–time profiles of the pulse were observed on a cathode-ray oscillograph. Light wires attached to the rubber cut the lines of force of constant strength magnetic fields which were produced by permanent magnets; the technique was similar to that described by Efron and Malvern[6]. Small amplitude pulses (<10 per cent) propagated along the rubber without measurable change in shape, but the front of larger pulses became sharper as they progressed along the band. Fig. 1 shows the change in shape of the velocity–time profile when the 10 inch length was extended to 11 inches, so that the strain in this section was 440 per cent (additional strain 40 per cent). When the pulse had travelled about nine feet, it may be regarded as a shock wave. Further work is being carried out on this problem. This work was supported by the Army Research Office (Durham).

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## Irradiation Creep in the Dounreay Fast Reactor

Helical springs, mostly from batches used in a thermal reactor irradiation[1] and loaded in tension in strings of five, have been used to measure irradiation creep in three experiments in the Dounreay Fast Reactor (DFR). The specimens were immersed in sodium and creep deflexions were estimated from pre and post-irradiation X-radiographs of the rigs. The deflexion of each spring was limited by design to about 15 mm. One nickel specimen, the uppermost in the second rig (Table 1) and of larger coil radius than the rest, was cut from a spring supplied by Dr R. V. Hesketh from the batch he used in his thermal irradiation[2]. For this spring a strain of $10^{-4}$ corresponded to a deflexion of 2·54 mm, twice that for the others, the comparison being for twenty-five active turns.

Table 1. RESULTS OF TESTS IN DFR

| Rig | Material | Neutron fluence > 0·82 MeV ($pm^{-2}$) | Stress ($MNm^{-2}$) | $N$ | $D$ (mm) |
|---|---|---|---|---|---|
| 1 (2,140 h) | 'Nimonic *PE*16' (*ST*) | 8·3 | 39 | 24·5 | 0·38 |
| | | 13·3 | 19 | 26 | 0·23 |
| | 316 Stainless steel (annealed) | 11·1 | 33 | 22·25 | 2·33 |
| | | 13·1 | 13 | 23·75 | 1·35 |
| | Molybdenum (*B*) | 13·0 | 26 | 26·5 | 8·56 |
| 2 (945 h) | Nickel (*C*) | 3·1 | 67 | 26·75 | ⩾18·57 |
| | 'Nimonic 80*A*' (*FHT*) | 4·7 | 33 | 20·5 | 0·56 |
| | Molybdenum (*D*) | 5·2 | 26 | 21·25 | 6·93 |
| | 'Nimonic *PE*16' (*ST*) | 5·4 | 20 | 21·75 | 0·30 |
| | 316 Stainless steel (annealed) | 5·1 | 13 | 22·25 | 0·46 |
| 3 (2,060 h) | 'Nimonic 80*A*' (*FHT*) | 10·2 | 60 | 19·75 | 3·00 |
| | 'Nimonic *PE*16' (*ST*) | 13·1 | 54 | 21·00 | 0·86 |
| | 316 Stainless steel (annealed) | 15·5 | 47 | 21·25 | 4·34 |
| | Molybdenum (*D*) | 16·1 | 20 | 22·0 | 7·06 |
| | Nickel (*E*) | 15·5 | 13 | 23·25 | 12·29 |

*D* is the creep deflexion and *N* the number of active turns, *ST*, annealed, and *FHT* as previously[1]; *B*, is 1 h at 1,095° C; *C*, as received; *D*, 1 h at 1,200° C; and *E*, 2 h at 700° C.

Laboratory control tests were of two kinds. The first, in air at 300° C, used apparatus previously described[3]. Enough tests were made before the irradiations to make it possible to choose stresses that would keep thermal creep tolerably small. Air tests were carried out for all materials in Table 1 at stresses between 25 and 40 $MNm^{-2}$. Deflexions were measured reproducibly to ±0·05 mm; the maximum amount observed, with one exception, was 0·13 mm ('Nimonic *PE*16', *ST*, 39 $MNm^{-2}$) although most specimens showed barely detectable changes. Each test lasted at least 1,000 h and where creep was detected it was transient. The exceptional result, a deflexion of 1·17 mm in 1,000 h and about double that amount after