A Density—Compression Modulus Relationship For Latex Foam

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The dependence of compression modulus of latex foam upon density over a fairly wide density range has been examined. An empirical expression for the relationship is put forward. This applies to unfilled natural rubber foams, to those containing a clay filler and to those prepared from a blend of natural latex with one type of styrene butadiene rubber latex.

In comparing the compression moduli of latex foams it is usually necessary to apply a correction for difference in density. When one latex, one formulation or one set of preparational conditions has to be compared with another in its effect on latex foam hardness, the usual procedure is to prepare foams covering a range of densities and to make the required comparisons from suitable interpolations in the compression modulus—density curves, a cumbersome procedure which could be simplified by knowledge of the equation of the curves. A theoretical derivation of this equation has already been undertaken by other workers on the basis of an idealised model, (GENT AND THOMAS, 1959). TALALAY (1954) has also derived an expression partly based on theory. The present contribution arose from observations in which a number of curves were established in detail by measurement of compression modulus at different densities for a variety of foams. A simple empirical expression was derived which allowed a fairly close prediction of compression modulus at any given density.

EXPERIMENTAL METHOD

The series of latex foams 1 to 11 (*Table 1*) were prepared from ammoniated natural rubber latex that had been concentrated by centrifugation to 60% dry rubber content: in the last two, 10 and 11, blends were made with styrene butadiene rubber latex 'Pliolite 5352'. Series 1 to 6 all used latex from one source; latex from a different source was used for 7 to 9 and for the NR component of 10 and 11. All foams were prepared under identical conditions according to a carefully controlled mixing and curing schedule. Each foam was cast in a mould producing twelve samples of equal size (approximately 3 × 2.5 × 1 in.) of which four were chosen at random for testing. Each series consisted of six to eight preparations over a density range of about 0.06 to 0.18 g per c.c. Foams were washed and dried for controlled periods and allowed to rest for 24 hours before being weighed, measured and flexed to 60% of their height 240 times, at a rate of 4 times per second. After resting a further 24 hours, compression modulus was measured. Preparation, resting and testing were carried out in an atmosphere controlled at 80 ± 1°F and 50 ± 2% R.H.

Measurement of compression modulus was made on a machine constructed in these laboratories, shown in *Figure 1*. The foam sample was placed on the balance platform, which had been reinforced against bending, and was compressed between this and a downward moving plate driven by a slow-speed motor through a clutch and screw-jack device. A dial gauge clamped to the compressor plate had its foot resting on the balance pan and indicated the relative movement between them. To ensure a known compression of the foam sample, the compressor plate was first brought

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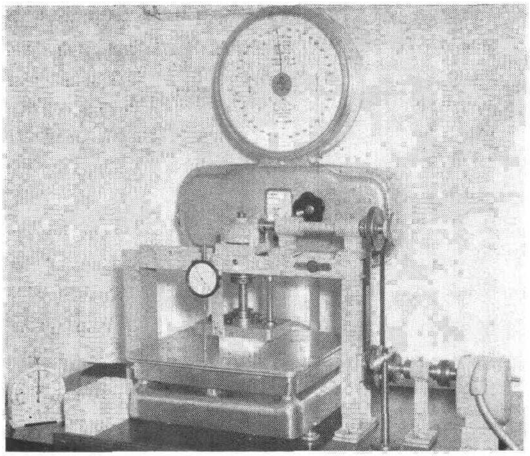

Figure 1. Machine for measuring compression modulus.

just in contact with the top surface of the sample and the balance and dial gauge readings brought to zero. Compression was started and continued until the required percentage of the original sample height was reached, at which point the load on the balance, i.e. the compressive force, was recorded. Correction was made for the force exerted by the dial gauge spring. Four samples were tested in each case and the mean taken. Compression modulus measurements were made at 50%, 40%, 25% and in some cases 10% compression with very good reproducibility. The same four samples measured again after a rest period of 24 hours gave a mean value within ± 0.1 g per sq. cm of the first measurement. This is small compared with the error of sampling in which the means of four samples selected in various ways from the twelve available varied within ± 1 g per sq.cm.

RESULTS AND DISCUSSION

In all the foam preparations examined the dependence of compression modulus on density could be represented by

$$C = A\ d^{n} \quad \ldots\ldots (1)$$

where C is compression modulus (in kg per cm²) at a given degree of compression, A is constant for a given latex and formulation at the same compression, d is the density (in g per c.c.) and n is a constant.

From (1), $\log C = \log A + n \log d \quad \ldots\ldots (2)$

Thus a plot of log C against log d is linear with slope n and with an intercept log A on the log C axis at d = 1.

Figure 2 shows log C plotted against log d for the foam series 1 at three degrees of compression. The degree of linearity is high and the slope only slightly dependent on the

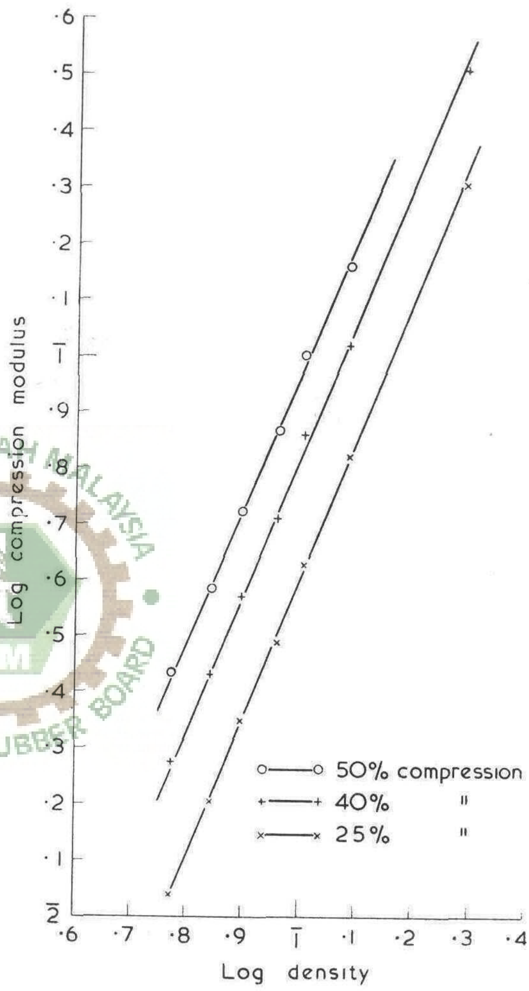

Figure 2. Foam series 1 at three degrees of compression.

compression. *Figures 3* and *4* show corresponding plots, at three degrees of compression, for foams containing 10 parts and 33 parts respectively of Devolite clay but otherwise prepared under identical conditions and from the same latex (series 2 and 3).

In these, as in the other series later examined, n varied only within narrow limits regardless of certain marked changes in formulation. For example foams prepared from a blend of natural latex and 33 parts (dry weight) of 'Pliolite 5352' (series 10) displayed

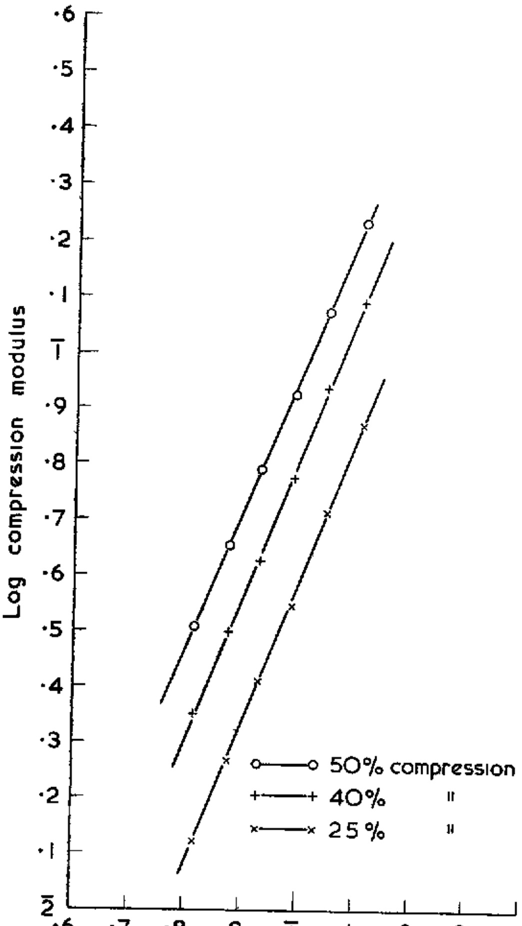

Figure 3. Foam series 2 at three degrees of compression.

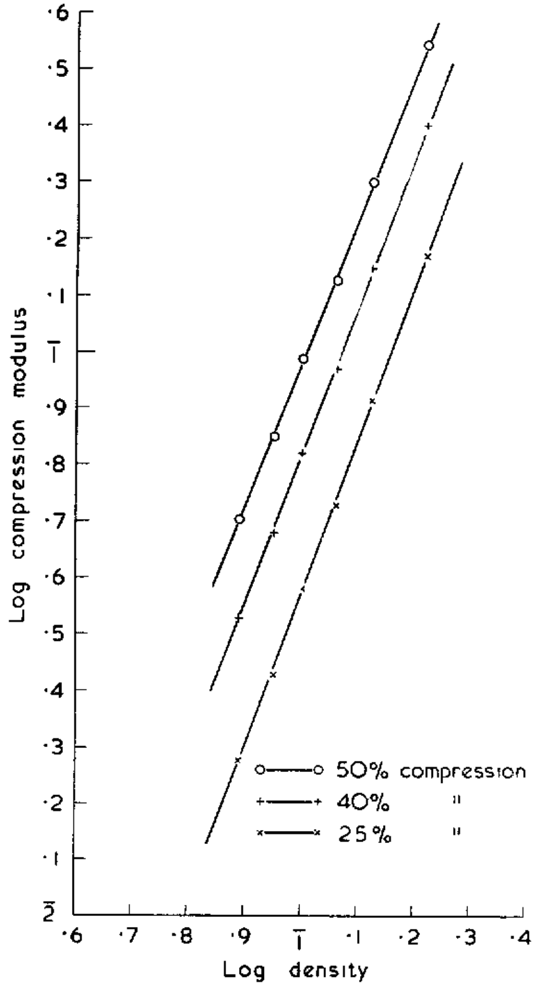

Figure 4. Foam series 3 at three degrees of compression.

the same linearity of log C against log d with a value of n close to that found for 100% natural latex foams. Replacing 90% of the natural rubber (dry weight) by 'Pliolite 5352' and making certain changes in formulation that this necessitated (Series 11), did not markedly affect the values of n (*Figure 5*).

The value of n appears to be determined mainly by characteristics of the structure of the foam itself as distinct from those of the bulk rubber. A on the other hand is mainly determined by the value of the bulk modulus

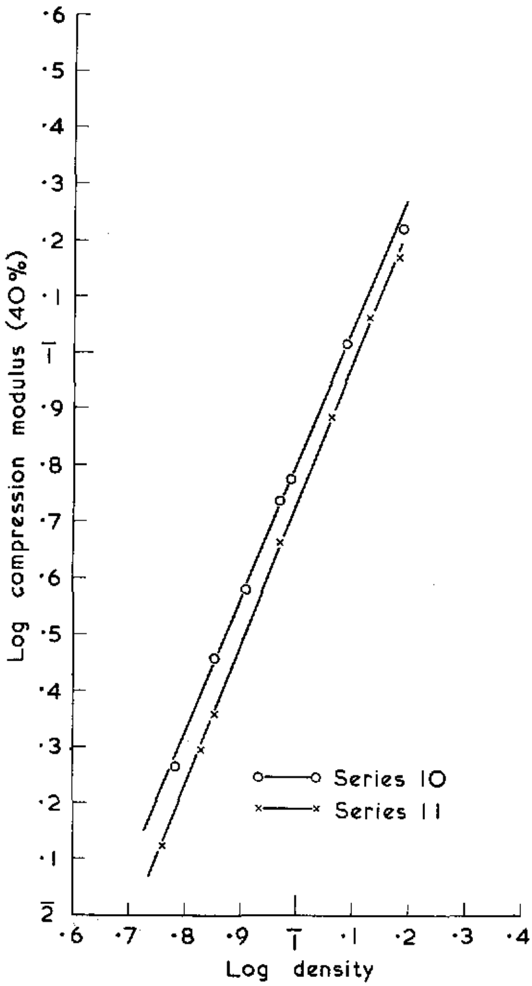

Figure 5. Foam series 10 and 11 at 40% compression.

and can vary very considerably. *Figure 6* for example, shows log C plotted against log d (at 40% compression) for the series 4, 5 and 6 which are identical in all respects other than the level of sulphur in the vulcanising formula (series 1 is included for comparison). A increases with sulphur level.

The incorporation of ammonium laurate in a foam formulation has been reported (GYSS, WOO AND CHAN, 1961) to modify the cell shape and thereby to enhance compression modulus. No important changes in n or A are displayed however by series 7, 8 and 9 which contain ammonium laurate in increasing amounts.

At d = 0.1 g per c.c., the compression modulus ($C_{0.1}$) is given by equation (2) which becomes log $C_{0.1}$ = log A − n. *Table 2* summarises the calculated values of n*, A and

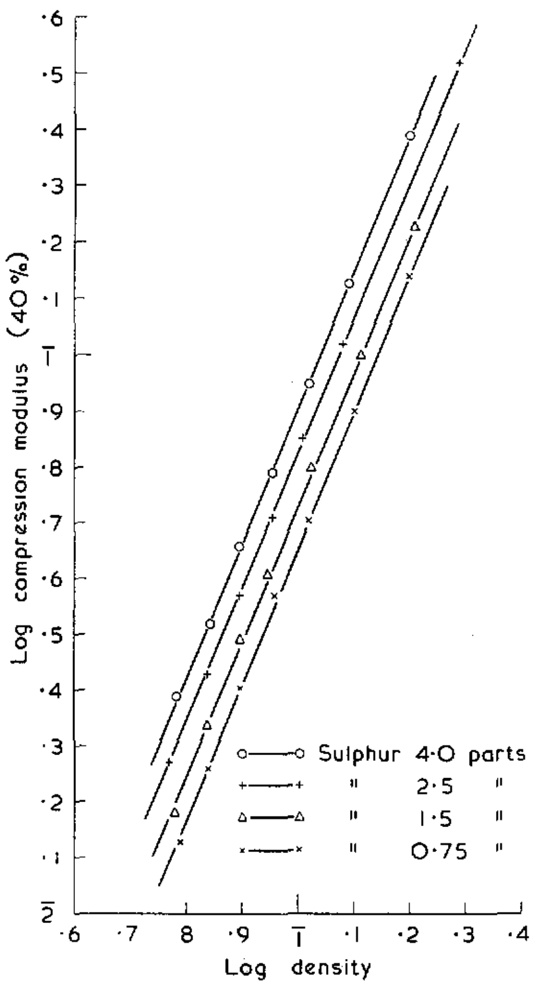

Figure 6. Effect of increasing sulphur level. Foam series 4, 5, 1 and 6.

* n was calculated by the usual least squares expression $(\Sigma xy - \Sigma x \Sigma y/N)/(\Sigma x^2 - (\Sigma x)^2/N)$ where x = log d, y = log C and N = no. of experimental points.

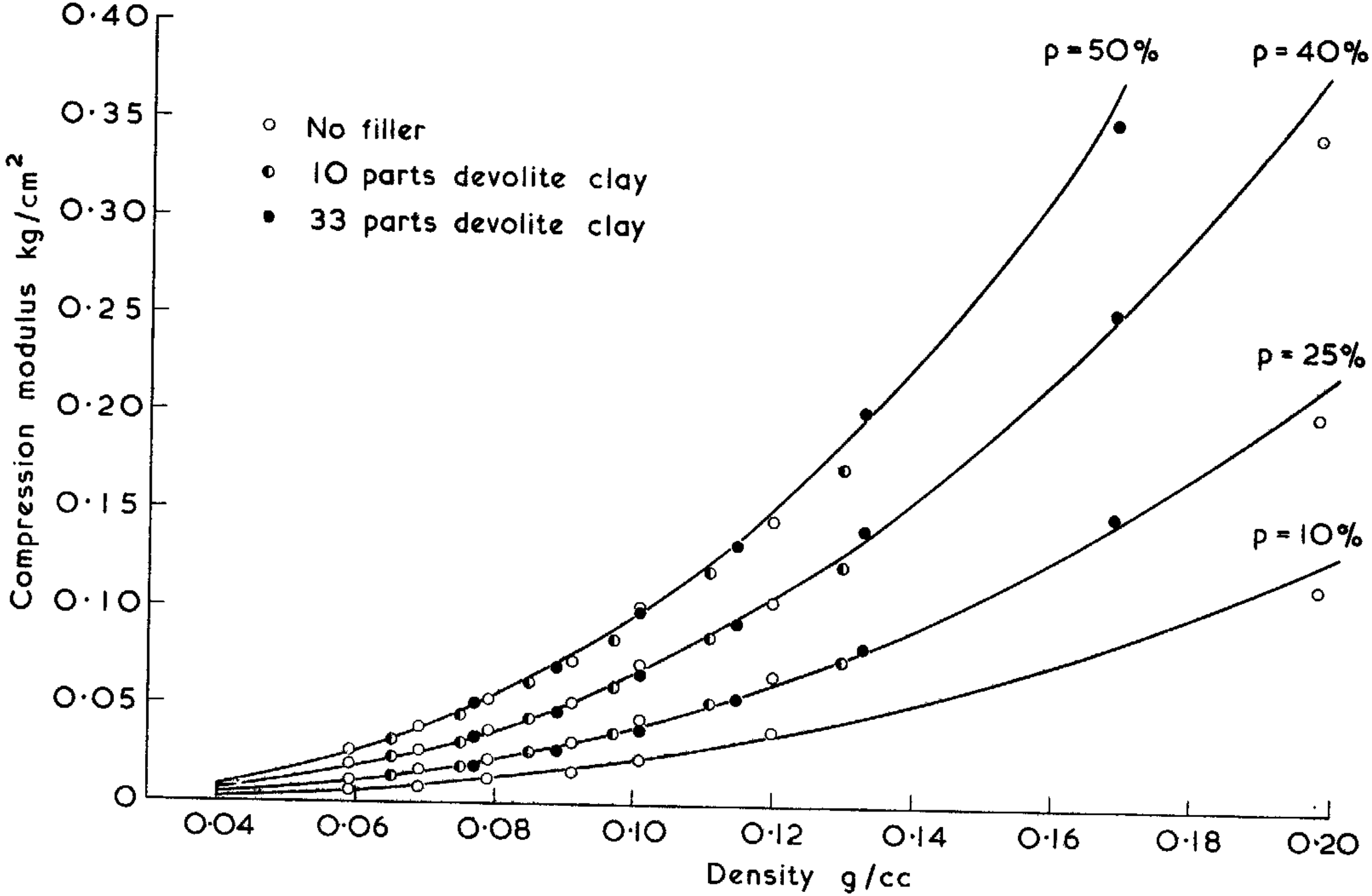

Figure 7. General expression log C = 0.728 + 0.0158 p + 2.54 log d at four values of p. Experimental points for series 1, 2 and 3 also shown.

$C_{0.1}$ at different degrees of compression for the series 1 to 11. We observe that n increases slightly with increasing filler loading and tends to decrease at higher degrees of compression. We can, however, as an approximation, use the mean value of n for all the series irrespective of degree of compression (n = 2.54).

For a given series of foams, i.e. of the same vulcanising formulation and made from the same latex, plotting log A against percentage compression (p) gives an approximately linear relationship for values of p from 15% to 50%. Hence we can substitute for log A in equation (2) and express C in terms of p, n and d. For example if we consider series 1, 2 and 3 together and recalculate the values of log A according to the general value of n = 2.54, then by plotting log A against p we obtain:

$$\log A = 0.728 + 0.0158\, p \qquad \ldots\ldots (3)$$

and equation (2) becomes

$$\log C = 0.728 + 0.0158\, p + 2.54 \log d \qquad \ldots\ldots (4)$$

Hence a series of plots of C against d, each corresponding to a given value of p can be constructed. These are given in *Figure 7* on which the experimental points are also shown. Thus it is possible to calculate the compression modulus at a given density and compression or to calculate the density required to produce a given modulus at a given compression in foams made from the same latex and formulation irrespective of the level of clay filler loading (from 0 to at least 33 p.h.r.).

A corresponding expression for foams from a different latex and/or formulation can therefore be obtained by: (i) measuring the compression modulus for a given degree of compression at two or more densities to derive the slope n. This step may be omitted if the mean value n = 2.54 is acceptable as an adequate approximation; (ii) measuring the modulus of a foam of a given density at 2 or more degrees of compression in the range p = 15% to 50%. Plotting the log A values thus obtained against p gives log A in terms of p. Substitution for log A in equation (2) gives the expression corresponding to equation (4).

Incorporation of 'reinforcing' fillers, e.g. ground mica, gives a non-linear relationship between log C and log d and the foregoing considerations do not apply.

ACKNOWLEDGEMENTS

An expression of the same form as (1) has been deduced independently, from unpublished work, by E. W. Madge at the Dunlop Research Centre and has been quoted recently (NAUNTON, 1961). The author thanks Mr W. G. Wren for his interest in the work, Mr Madge for helpful correspondence, Mr Foong Seng Kit and Mrs Goon Kok Leng for experimental assistance and Messrs D. R. Westgarth and G. C. Iyer for statistical advice.

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Kuala Lumpur *July 1962*

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TABLE 1. VULCANISING FORMULAE FOR FOAM SERIES 1 TO 11

Ingredients	Series number										
	1	2	3	4	5	6	7	8	9	10	11
Rubber	100	100	100	100	100	100	100	100	100	75 NR 25 SBR	10 NR 90 SBR
Potassium oleate	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25
Ammonium laurate	—	—	—	—	—	—	—	0.1	0.3	—	—
Sulphur	2.5	2.5	2.5	0.75	1.5	4.0	2.5	2.5	2.5	2.5	2.0
Zinc oxide	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0
Z.D.C.	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.75
Z.M.B.T.	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.5
Devolite clay	—	10	33	—	—	—	—	—	—	—	—
Vulcafor EXN	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vulcastab TM	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	—
Ammonium chloride	0.6	0.6	0.6	0.6	0.6	0.6	0.20	0.20	0.20	0.25	—
Vulcafor EFA	—	—	—	—	—	—	—	—	—	—	1.0
ZnO/DPG (1:1)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	—
S.S.F.	1.6	1.6	1.6	1.6	1.6	1.6	1.25	1.25	1.25	1.6	3.5

TABLE 2. VALUES OF n, A AND $C_{0.1}$ AT FOUR DEGREES OF COMPRESSION, FOR FOAM SERIES 1 TO 11

$C_{0.1}$ given in kg per sq. cm.

Series no.	10% compression			25% compression			40% compression			50% compression		
	n	A	$C_{0.1}$	n	A	$C_{0.1}$	n	A	$C_{0.1}$	n	A	$C_{0.1}$
1	2.69	10.8	0.0222	2.54	14.2	0.0411	2.45	18.9	0.0675	2.39	23.3	0.0947
1 (fatigued) *	2.61	7.6	0.0186	2.53	11.7	0.0347	2.48	18.8	0.0623	2.41	23.4	0.0920
2				2.53	13.3	0.0390	2.50	20.3	0.0647	2.45	25.8	0.0917
2 (fatigued) *				2.56	11.8	0.0327	2.57	22.0	0.0599	2.47	26.0	0.0891
3				2.66	17.2	0.0375	2.60	26.0	0.0653	2.49	29.6	0.0961
3 (fatigued) *				2.69	14.9	0.0304	2.64	25.7	0.0591	2.50	28.7	0.0914
4	2.74	9.0	0.0165	2.58	10.6	0.0278	2.49	13.8	0.0451	2.43	17.1	0.0634
5	2.65	8.7	0.0197	2.55	11.9	0.0335	2.46	15.6	0.0540	2.43	20.4	0.0767
6	2.67	12.5	0.0270	2.53	16.1	0.0478	2.45	22.0	0.0781	2.38	26.3	0.1098
7	2.55	7.0	0.0196	2.59	13.7	0.0349	2.53	19.3	0.0577	2.52	27.4	0.0822
8				2.64	15.2	0.0351	2.56	21.3	0.0590	2.50	26.6	0.0846
9				2.60	13.9	0.0350	2.51	19.1	0.0597	2.47	25.3	0.0850
10	2.67	9.0	0.0192	2.49	11.5	0.0371	2.38	15.1	0.0622	2.34	19.1	0.0874
11	2.76	7.7	0.0135	2.67	13.9	0.0300	2.55	18.8	0.0535	2.48	23.1	0.0764

* After 250,000 compressions (at 4 per sec.) to 60% of original height.