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SHORT COMMUNICATION

A Novel Method for Determining the Compression Modulus of Rubber Vulcanisates

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A novel method for determining the compression modulus of rubber vulcanisates is described. The machine is simple and inexpensive. The test is rapid and the results are highly repeatable being relatively free of operator dependence. It is potentially a useful quality control test.

One of the curious features of physical testing of rubber is the fact that while the majority of applications of rubber, particularly in engineering, involve relatively small deformations in compression and shear, tensile properties at large strains are most often measured in rubber laboratories around the world. Indeed, few laboratories are equipped to measure compression and shear moduli and even those that are so equipped make such measurements rarely compared with the frequency of tensile measurements. This is a great pity since testing in compression and shear is clearly most relevant for many applications. Further, it is a well-known fact that the markedly non-linear elastic properties of rubber prevent accurate prediction of behaviour at small-to-moderate strains in compression and shear from data obtained at large strains in tension.

Among the reasons for the lack of popularity of compression and shear measurements is the inconvenience of doing the test. It is usual to use a sophisticated universal testing machine, there being a lack of suitable purpose-built machines. These are expensive machines, outside the reach of many small laboratories which are primarily interested in quality control. Further, these universal machines are inconvenient to set-up for such work.

There is a need for a simple, inexpensive machine capable of estimating compression or shear modulus precisely and rapidly. Such a machine has been designed and built for compression modulus. It is described below.

Principle of Design

The operating principle of the present instrument is the application of a defined deflection to a standard size test piece and the simultaneous measurement of the force. The Young's modulus or alternative elastic constants can be readily calculated from the force, deflection and test piece dimensions.

Implementation of the Design

The chosen test piece is a cylinder nominally 29.0 mm in diameter and 12.5 mm in height.

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This is the larger of the two standard test pieces used in the ISO compression set test[1] and is also the standard test piece in the proposed ISO compression stress-strain test[2]. It is necessary for the present purposes to maintain a tighter tolerance on dimensions than permitted in the above mentioned ISO test methods. Hence, the test piece must be prepared by moulding.

The diameter of these test pieces when moulded in conventional moulds depends only on the dimensions of the mould and the amount of shrinkage. The amount of shrinkage is usually small and, moreover, reasonably constant between rubbers. Thus, provided the diameter of the mould cavity has been specified to close tolerances, the diameter of the test piece may be taken to be constant with little error.

The height of the test piece tends to be variable due to variation in flash thickness. It is possible to minimise this by using transfer or injection moulding but even so, normal wear of the mould will alter this dimension. Hence, the height of each test piece must be measured. A dial gauge[3] is used to measure this dimension to within 0.01 mm.

The mechanical design of the machine is shown schematically in *Figure 1*. An essential part of the design is the robust annular wall that surrounds the load-cell. It is seen that this wall together with the platen of the load-cell and the top-plate when closed by actuation of the pneumatic cylinder form a cell of defined height. Thus, the height of this wall above the platen of the load-cell defines the amount of deflection imposed on the test piece. This height may be chosen to give any realistic deflection. For the present implementation, the height is a nominal 11.3 mm; that is about 90% of the nominal height of the test piece corresponding to a nominal compressive strain of 10% consistent with one of the preferred strains in the ISO proposal[2]. This height is measured to 0.01 mm with a depth micrometer.

Rigidity in construction is essential to the design. The weak link is the load-cell. An over-soft load-cell will result in a small but significant deflection in the platen of the load-cell under load. This will entail some ambiguity in the strain. Fortunately, modern electronic load-cells are very stiff. Further, a load-cell of higher load carrying capacity has been selected. This means that the load-cell will operate over only a portion of its rated loading capacity sacrificing some precision in load measurement for lower compliance.

The load-cell chosen is an Interface* Model 1010 low profile load-cell. This has a rated compliance corresponding to a deflection of 0.01 mm at its rated capacity of 2 kN. At the maximum design load of 1 kN, the deflection is negligible being less than the precision with which the height of the test piece is determined.

Conventional electronic circuits are used to obtain a digital read-out of the force on the load-cell.

Operating Procedure

The test piece height is first measured. It is then lubricated on both flat surfaces with a thin smear of silicone fluid before placing on the platen of the load-cell. This is in order to avoid complications arising from shape factor considerations[4] which come into play when the loaded surfaces are restrained by friction. This procedure is in accordance with one of the standard procedures in the proposed ISO standard test[2].

The pneumatic cylinder is then actuated to close the top platen. As rubber is a visco-elastic material, the force exerted by the test piece on the load-cell varies with time after application

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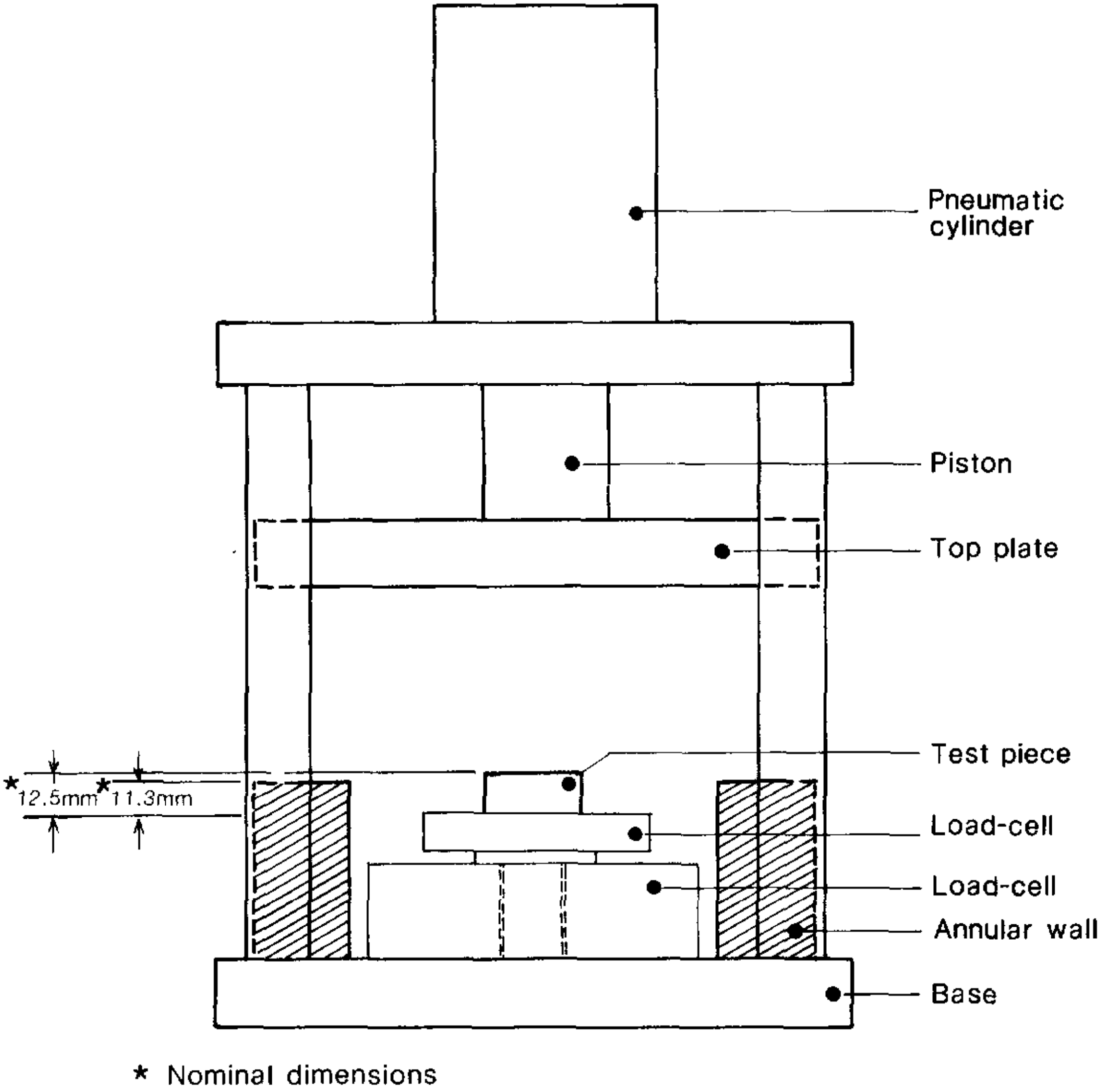

Figure 1. Schematic diagram of apparatus.

of the fixed deformation. Indeed, the present instrument can operate as a simple, single station stress relaxometer. The force reading is arbitrarily taken after 1 min. This period is chosen as a compromise between rapid testing and reasonably repeatable results.

Expression of Results

It is possible to calculate Young's modulus of the rubber by using the stress/strain relationship predicted by the statistical and phenomenological theories[5] of rubber elasticity. However, the ISO proposal[2] recommends the expression of the result as the simple ratio of applied stress divided by strain. This is sometimes called the chord modulus. This method of expression of results is adopted here.

Precision of Test Results

In any test method, the precision of the test result is of importance. In the present method, there is reasonable doubt as to the efficiency of the silicon lubricating fluid in eliminating friction. This can be a major source of variation in the test result.

Table 1 shows the results of a typical test on six replicate test pieces of a rubber vulcanisate. The coefficient of variation is of the order of 1.5%.

TABLE 1. RESULTS OF A TYPICAL TEST ON SIX REPLICATE TEST PIECES

Test piece No.	Height[a] (mm)	Strain[a] (%)	Chord modulus (MPa)
1	12.78	10.41	7.31
2	12.70	9.84	7.54
3	12.74	10.13	7.38
4	12.71	9.91	7.54
5	12.75	10.20	7.38
6	12.70	9.84	7.54
Mean C.V.	—	—	7.45 MPa 1.4%

[a]The height of the annular wall above the load-cell platen was 11.45 mm somewhat larger than the nominal 11.3 mm. This is because existing moulds yielded cylinders slightly taller than the nominal height. It was less convenient to modify the existing moulds.

The most critical measurement as far as errors are concerned is the measurement of the test piece height. This cannot be estimated to an accuracy of better than ± 0.01 mm. Considering that the imposed deflection is about 1.3 mm, an error of 0.01 mm in the height means an error of 0.8% in the chord modulus. Thus, the best precision of the test method cannot be much better than $\pm 1\%$. The achieved coefficient of variation of 1.5% is therefore highly satisfactory and indicates that efficient lubrication is being achieved.

Operator Variability

An ideal test method should have no operator dependence. *Table 2* shows the results of a test on operator variability. Six nominally identical test pieces were taken from each of three different vulcanisates. These were tested in turn by five novice operators**. The between operator differences are clearly very small showing virtually no operator dependence inspite of the fact that none of the operators had previous experience with this test.

Accuracy of Test Results

Although the test is very precise, it must be pointed out that it is somewhat less accurate

**The test is essentially non-destructive apart from development of a small (but significant) amount of set during the first deformation cycle. The test pieces were therefore conditioned by performing the test a few times before they were distributed to the five operators. Previous trials with a single operator showed that test pieces conditioned in this manner did not change significantly during the course of a limited series of repeated tests.

TABLE 2. RESULTS OF A TEST ON OPERATOR DEPENDENCE

Operator No.	Rubber 1		Rubber 2		Rubber 3	
	Mean (MPa)	C.V. (%)	Mean (MPa)	C.V. (%)	Mean (MPa)	C.V. (%)
1	2.95	1.5	5.20	0.7	7.67	1.1
2	2.96	1.5	5.21	1.1	7.66	1.2
3	2.95	1.2	5.18	0.8	7.61	1.1
4	2.97	1.0	5.16	0.8	7.62	1.5
5	2.96	1.2	5.18	0.6	7.65	1.3
Mean	2.96	1.3	5.18	0.08	7.64	1.3

than the precision. It is seen from *Table 1* that the heights of the test pieces are not constant. Consequently, the test strain is not at a constant 10%.

It was found that when a large range of rubber is to be tested, unless extra care is taken during test piece moulding, it is impracticable to expect a tolerance on test piece height better than ± 0.3 mm. This is because rubbers of different densities require different moulding blank weights. Also rubbers have different flow characteristics. These factors affect the thickness of the flash in conventional compression moulds and hence the height of the test pieces varies.

Variation of ± 0.3 mm in test piece height corresponds to test strains of 8% to 12%. Because of the non-linearity of the stress/strain curve, the chord moduli at 8% and 12% will be different from the chord modulus at 10%. Fortunately, the maximum error from this source is only about $\pm 2\%$. Further, when only one rubber is repeatedly tested (e.g. in quality control) the variation in test piece height can be minimised and the errors correspondingly smaller. Nevertheless, it is prudent to be aware of this source of inaccuracy in the results.

Applications

The test is basically very simple to perform and quite rapid. The machine is inexpensive. The results are also highly repeatable making the test ideal as a quality control tool.

An attractive feature is the possibility of a high degree of automation. Compared to conventional quality control tests, the present method lends itself readily to full automation.

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