Paper No. 131

"Understanding the IRHD and Shore Methods used in Rubber Hardness Testing"

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Presented at a meeting of the
Rubber Division, American Chemical Society
Orlando, Florida
September 21-24, 1999

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ABSTRACT

Hardness is one of the most widely measured properties used to characterise rubber. Two scales are in general use throughout the world – the IRHD (International Rubber Hardness Degree) scale and the Shore scale. The two test methods use totally different indentor geometries, applied forces, test times and procedures. Instruments exist for most of these scales – both as tabletop instruments and hand held versions - with little knowledge of the differences between them. National and international standards exist for most of these instruments; however, there are also some subtle differences between these standards. This paper looks at the instruments in question, studies the differences between the tests and their relationship between scales where possible. This paper also highlights the merits of each instrument and test type. In cases where measurements must be made on small or awkward production samples, the test method and sample dimensions may be highly significant and it is important to know the limitations of each test method. In conclusion, this paper aims to create a clear understanding of hardness testing methods and the results they provide.

INTRODUCTION

Hardness is one of the most widely measured properties used to characterise rubber. The IRHD (International Rubber Hardness Degree) Scale and the Shore Scale are widely used. A number of instrument types exist for both – the IRHD Micro/Dead Load and Shore A scales are most commonly used for rubber. Both methods are described in international standards.[1, 2]

The two test methods use totally different indentor geometries, applied forces, test times and procedures. The IRHD test is usually non-destructive, and as such has to be the preferred method for final product inspection; the test takes 35 seconds. In contrast, the Shore method is often destructive (leaving a permanent indentation), but the test only takes 1 or 3 seconds. The paper begins with a historical look at the instruments and the degree of correlation between them.

Instruments exist for most of the IRHD and Shore scales, both as tabletop and hand held versions. The IRHD Dead Load has a Micro counterpart, which has had an established standard for over 30 years (ISO 48[1] & ASTM 1415[2]). The proposed Shore Micro does not yet have a released standard. The Micro IRHD instrument was introduced in the 1950's as a scaled down version of the IRHD Dead Load – used for testing thinner, smaller samples and products. The Micro IRHD results are generally comparable to those given by the standard IRHD Dead Load instrument. In contrast, there are various Shore M scale instruments appearing on the market; some constructed quite differently. The Shore M results are generally not comparable to those obtained from the Shore A scale.

Experience has shown that a degree of confusion exists between some users of the two scales. This paper highlights the merits of each instrument and test type. In cases where measurements must be made on small, awkward or curved production samples, the test methods and sample dimensions may be highly significant and it is important to know the limitations of each test method.

In summary, this paper aims to create a clear understanding of common hardness testing methods and the results they provide.

HISTORICAL PERSPECTIVE

According to Bassi et al[3] the Shore instruments had historical priority over the IRHD instruments by more than 30 years. Gurney[4] reported both instruments in use by the early 1920's, together with other spring and dead load (weight) variants. Results from the spring type varied with the user (Gurney[4], The Rubber Age[5]). This lead to the adoption of the dead load instrument where the indentation depth was largely user independent. After Scott[6] stressed the need for a standard to give results some common meaning in 1935, the first British Standard (BS) was introduced in 1940. At the same time, Scott and Newton[7] reported on a reliable pocket type hardness gauge that conformed to this new standard. After a comparison with the Shore A Durometer, they concluded that the advantage was always with the BS Hardness Meter. Work was then carried out looking at different instrument types (Daynes and Scott[8]) and the new standard (Scott[9]). They both agreed that there was some correlation between the Shore A and BS hardness scales.

The accuracy of a range of hardness testers (Newton[10]) was investigated, concluding that the main limitations were associated with the operator. Instruments with a spherical indentor and foot gave the smallest errors; the largest errors were associated with the Shore durometer. The largest source of variation reported by Scott[11] was the lack of agreement between laboratories.

The Micro Hardness Tester, a (1/6th) scaled down version of the IRHD Dead Load Hardness Tester was introduced in the 1950's to test thinner and small production samples. Scott and Soden[12] reported results comparable between the Micro and Dead Load tests, with only a few degrees difference noted for rubbers of greater than 65° hardness.

Several papers[3, 13, 14, 15] published in the 1960's, 70's and 80's and two books, Rubber and Plastics Testing[16] and Physical Testing of Rubbers[17] stated that the most widely used instrument was then the Shore A type even though the IRHD method produced more repeatable results between operators, with higher accuracy, reproducibility and precision. However, Shore A has a less critical dependence than IRHD on sample thickness (Bassi et al[3]). Comparative work by Brown and Soekarnein[18] (1991) between the IRHD Dead Load, IRHD Micro and Shore A instruments demonstrated that inter-laboratory repeatability was likely to be best for the IRHD Dead Load and Micro instruments. In 1993, Briscoe and Sebastian[19] analysed the durometer indentation, providing an approximate relationship between IRHD and Shore A of ($IRH \approx H_A + 4$), although this is very dependent on the sample compound.

Many contemporary hardness testers have improved accuracy due to the automatic nature of the test, requiring minimal operator intervention. Bench mounted instruments (IRHD Dead Load and Micro and Shore A scales) produce the most repeatable and reliable results. Pocket meters are much improved, but do rely entirely on the operator's hand pressure and reliable angular application for repeatable results (variations can be extreme).

In recent years, there has been an increased interest in the Shore M instrument, although there is no published standard. There are a variety of these instruments on the market from several suppliers and some are constructed quite differently. Recently, Wallace has manufactured Shore M instruments to the best draft information available. The results are not comparable to those obtained from a Shore A instrument.

DIFFERENCES BETWEEN IRHD AND SHORE INSTRUMENTS AND RELATIONSHIPS BETWEEN SCALES

There are four IRHD methods in use: the Normal-hardness test (Dead Load), High-hardness test, Low-hardness test and the Micro-test. The Normal test is used for samples greater than or equal to 4mm thick and preferably used for rubbers in the 35 to 85 IRHD range (but with reservation, may be used for the 30 to 95 IRHD range). The High-hardness test is used for testing samples of the same dimensions as the Normal test, but in the 85 to 100 IRHD range. The Low-hardness test is used for testing samples greater than or equal to 6mm thick and hardnesses in the 10 to 35 IRHD range. The Micro tests samples less than 4mm thick and is used for rubbers in the 35 to 85 IRHD range (but with reservation, may be used for the 30 to 95 IRHD range). All four methods use a spherically tipped indentor. The diameters of the ball indentor and foot vary between methods. The applied forces are the same for the Normal, High and Low tests, with only the Micro test requiring the application of smaller forces. It is worth noting that the IRHD scale is non-linear.

The Shore range of hardness testers incorporates eight scale types: A, B, C, D, DO, O, OO and M. These are used for testing a wider range of materials. The A scale is used for soft rubbers and elastomers and type C for medium hard rubbers and plastics; both types use a truncated cone shaped indentor. Type A is the most commonly used rubber scale. Type B is used to test moderately hard rubbers and type D is used to test hard rubbers and plastics. Both of these use a 30° indentor. Type DO is used for very dense textile windings, type O is used for soft rubbers and medium density textiles and OO is used for low density textile windings and sponge. These three use a 3/32 inch spherically ended indentor. All types require samples more than 6mm thick (unless it can be proved that smaller samples give equivalent results). Type M (no published standard yet) is used for testing thin and irregular rubbers of hardness in the range 20 to 90 and uses a very small round tipped indentor. Thinner samples may be used, although the support table starts to affect the value as thickness falls as the indentor penetrates the sample. Spring forces vary between instruments. Type A, B and O use the same spring force and it is recommended that a force equivalent of 1kg is applied to the durometer to ensure that the spring force is repeatably overcome (note that the DIN standard uses 1.27kg and tighter indentor dimensional limits). Type C, D and DO use the same spring, requiring a force equivalent of 5kg to overcome the spring. Type OO uses a different spring and requires 400g. Type M currently suggests a force suitable to overcome the calibrated spring force. All Shore scales are linear.

The IRHD method is based on the use of dead loads (weights). A foot is used to hold the sample in place with a force of 8.3N (Dead Load) or 235mN in the case of the Micro hardness tester. A primary load of 0.3N (Dead Load) or 8.3mN (Micro hardness tester) is then applied for 5 seconds, providing a datum position. A secondary load of 5.4N (Dead Load) or 145mN (Micro) is then applied for 30 seconds. The incremental displacement from the datum is measured and converted to an IRHD value (a non-linear scale defined in the standard). The full-range displacement of (Normal) Dead Load is 1.8mm; the Micro uses 0.3mm.

In contrast, the Shore instruments use calibrated springs. For example, the Shore A scale spring force varies from 0.5N to 8.1N (over the full displacement) and the Shore M scale from 0.3N to 0.8N. The presser foot applies a force sufficient to overcome the spring force. Once the presser foot contacts the sample the indentation depth is recorded after a pre-set dwell time; the standard ASTM dwell times are 1 and 3 seconds. The DIN standard uses 3 seconds, since the reading is usually still changing appreciably after 1 second. The force increases linearly with indentor displacement (full range is 2.5mm for the A scale and 1.25mm for the M scale).

The IRHD scale was set in 1948 to correspond to the Shore scale, in that a high number indicates a hard rubber and a low number indicates a softer rubber. The original Micro hardness test was designed to be a scaled down version of the Normal Dead Load test (displacements in the ratio 6 to 1). The forces applied were in the ratio 36 to 1. Therefore if the limited thickness sample tested in the case of a Micro instrument is $1/6^{th}$ of the thickness of the Dead Load piece, $1/6^{th}$ of the result is obtained. Scaling is set so that the same result should be obtained from both instruments. Similarly, results from the Normal, High and Low Dead Loads show correlation.

The Shore M test was not designed as a scaled down version of the Shore A test, but merely as an instrument that was capable of testing smaller samples. It uses an unrelated indentor and spring; there is no easy relationship between the two instruments.

EXPERIMENTAL

It follows from the above discussion that results obtained from hand-held durometers are not reliable due to operator dependence. Therefore, only bench mounted instruments were used to obtain the experimental results; however, the conclusions drawn will also be relevant to hand held instruments. Since the majority of rubber and elastomers use the Shore A and M scales, other Shore scales will be disregarded in this paper. These two instruments are also the main counterparts of the Normal and Micro IRHD instruments.

All instruments were calibrated before starting and the calibration was rechecked at the end. A standard temperature of 23±2°C was used (except where otherwise noted). The Shore instruments were set to both 1 and 3 second dwell time (since the results from these times differ). Test times are defined by the standard for the IRHD instruments (5 and 30 seconds). Each flat sample was tested in 5 different places and curved samples were tested as specified below.

A previous paper[20] compared the Micro IRHD and Micro Shore instruments, looking at the effects of sample thickness, lateral dimensions, bent samples, temperature, re-testing a previously measure spot and the effect of the foot force on the Shore M instrument. The current paper aims to continue and extend this work to include the Dead Load and Shore A instruments as well as incorporating results from curved surfaces.

Standard Wallace test blocks (varying compounds of natural rubber, supplied by MRPRA) for both dead load and micro instruments were used to provide comparative results for each instrument.

The previous work[20] on sample thickness was limited and therefore this is now investigated in further detail. The ISO standard[1] allows 1mm thick samples to be used but the preferred thickness is 2 ± 0.5mm. It is known that Shore M has similar requirements. Tests were performed on a range of thinner materials. The Shore standard[2] suggests that samples be plied to increase their effective thickness; this was done to determine the effect of varying sample thickness. This was extended to similar work on the IRHD dead load and Shore A instruments. The IRHD standard thickness is 8-10mm whilst the Shore A is 6mm. A selection of thinner samples were tested and plied to determine the effect of varying sample thickness.

Previous work[20] with the Micro instruments included an investigation into the effect of increasing the ambient temperature. Therefore tests were carried out on the Dead Load and Shore A instruments at a raised temperature to determine any effect.

Curved samples, such as 'O' rings, are often tested and the effect of testing these on different instruments was investigated. 'O' rings (of varying outer and core diameters) were placed on a specially designed table so that they could be accurately displaced laterally to determine the effect of testing away from the top dead centre.

RESULTS

Standard Test Blocks

The standard test blocks gave repeatable results using Micro and Normal Dead Load instruments. The 1 and 3 second dwell times (Shore A and M) produced equivalent and repeatable results. The Dead Load readings were consistently a few units higher than the Shore A readings over the range tested (40 – 90 IRHD). However, there was an increasing tendency for the Shore M results to diverge from the Micro IRHD result with increasing hardness values.

Effects of Thickness

The IRHD Dead Load and Shore A instruments were used to test the standard Wallace Micro samples (2mm thick). As expected, the results differed from those obtained using the specified instrument for the sample thickness, i.e. the Micro IRHD and the Shore M types. The softer rubbers, and also the IRHD Dead Load instrument, exhibited greater differences between the micro and macro instrument results. For the hardest rubber (76-79 IRHD), the IRHD Dead Load instrument gave a very close value (see figure 1). The Shore A instrument read a few units lower as expected but the readings were closer between the Shore A and Shore M instruments. The Shore A value of the hardest rubber differed by only 1 unit to the Shore M value (figure 1).

Once the 2 mm thick samples were plied to 8mm thick (the standard thickness required for the IRHD Dead Load tester) the results came within the specified tolerances of the test pieces. Increasing the thickness further made little difference to the result. Using the Shore A instrument, the results after plying pieces to provide a 6mm thick sample (the standard thickness for Shore A) was not equivalent to the value when tested with a Shore M instrument. See figure 2.

In contrast, the standard Dead Load blocks of 8mm thick, when tested on the Micro IRHD and the Shore M instruments, tended to give approximately the same results as the Dead Load IRHD and Shore A instruments.

Various thinner samples were used with the micro instruments. Up to 5 pieces of neoprene (0.6mm thickness) were plied, taking the thickness of the sample into the standard tolerance region (and slightly beyond). Both the IRHD Micro and Shore Micro showed a continual decrease in hardness with increasing thickness (see figure 3). As before, the IRHD hardness values were consistently higher than the Shore M values. For a nitrile sample, the readings at the initial thickness of 1.5mm (within the tolerance given in the standard) were similar between instruments. The Shore M results remained constant during the thickness increase but the IRHD Micro instrument showed a decrease in hardness with increasing thickness to 4.5mm. In the case of a sample of silicone, the Shore M results were consistently lower than the IRHD Micro values, but both instruments exhibited a decrease in hardness of 1 unit, when doubling the thickness of the sample from 0.9mm to 1.8mm (within the standard).

Effect of Temperature

Raising the temperature by 10°C appeared to make little difference to the results from the IRHD Dead Load on the standard test blocks (natural rubber compound). However, slightly lower values were observed on the harder samples tested on the Shore A instrument.

Effect of Curved Surfaces

The smaller diameter 'O' rings were laterally displaced in increments of 0.25mm. The larger curved surfaces were displaced in increments of 0.5mm. Graphs were plotted, showing the change in apparent hardness as the sample was displaced across the indentor. In general, the resulting curves on the graphs were flatter when testing the 'O' Rings on a Micro IRHD instrument than on the Shore M instrument. The Shore M instrument produced curves which were more peaked, with the hardness values rapidly decreasing on either side of top dead centre (figure 4).

A piece of pipe (8mm diameter) was tested on the IRHD Dead Load and Shore A instruments; both gave fairly flat curves. An EPDM 'O' ring of core diameter 7.8mm produced a gentle curve when tested on the Shore A instrument, but when tested on the IRHD Dead Load, it was inverted.

DISCUSSION

From the results it is clear that there is a correlation between the Dead Load and the Micro IRHD instruments. This is apparent when the IRHD Dead Load result of plied micro samples corresponds with the standard result on an IRHD Micro instrument. In contrast, the same cannot be said for the Shore A and M scales.

The results indicate that the thickness of the sample used on the IRHD Dead Load affects the result more than on the Shore A, in agreement with Bassi et al[3].

In general, when the nitrile, neoprene and silicone samples were plied, a trend of decreasing hardness with increasing thickness was observed. Some differences were noted and it appears that different rubber types influence the results in slightly different ways. More extensive work is required in this area.

Generally, the micro instruments can be used for testing both micro and macro samples, whilst the macro instruments (IRHD Dead Load and Shore A) are better for macro samples. Indeed, many people now use the Micro IRHD instead of the Dead Load instrument.

Flatter curves are produced with the IRHD Dead Load, Micro and the Shore A instruments when testing curved samples, implying that there is less critical dependence on accurate sample positioning with these. Since the graphs produced when using the Shore M instrument are more peaked, it is important to accurately place the sample (to within ~ 0.1mm). However, this is controlled when using an instrument attachment to centralize 'O' rings, but remains important when testing curved shapes that cannot be held accurately in such an attachment.

Increasing the temperature by approximately 10°C appears to make a greater difference to harder natural rubber samples only on the Shore A and little difference using the IRHD Dead Load instrument. This compares to a slight effect noted in the previous work[20] with both the IRHD Micro and the Shore M instruments.

From previous work, it is clear that repeated testing at the same location makes an appreciable difference to the results. This is more apparent when using the Shore M instrument. It is important to ensure that the sample is displaced between tests – this can be difficult for small samples.

It is interesting to note that the results obtained from the Shore instruments with a dwell time of 3 seconds differ from those obtained using 1 second. This effect was demonstrated more effectively in previous work[20]. Therefore, for Shore instruments, although different timings are unimportant for comparative work, it is important that the timing is accurate and repeatable. The time required (35 seconds specified by the standard) for an IRHD test places the IRHD instruments at a disadvantage. However, previous work by Lackovic et al[21] indicates that this time can be reduced by a predictive technique, taking it into direct competition with the Shore timing, i.e. 3 seconds.

CONCLUSION

This paper has taken a historical look at the IRHD and Shore Hardness measurement instruments as well as discussing and emphasising the fundamental differences between the most common instruments used for rubber and elastomer hardness characterisation. As demonstrated in a previous paper[20], the various instruments exhibit advantages and disadvantages with certain sample types. IRHD instruments are preferred for non-destructive testing and the Micro IRHD is generally a better choice for testing curved surfaces. The Shore A instrument is preferable for testing non-standard thickness samples and when shorter test cycle times are required. Accurate and repeatable timing is critical to allow Shore A and M instruments to provide consistent and comparable results.

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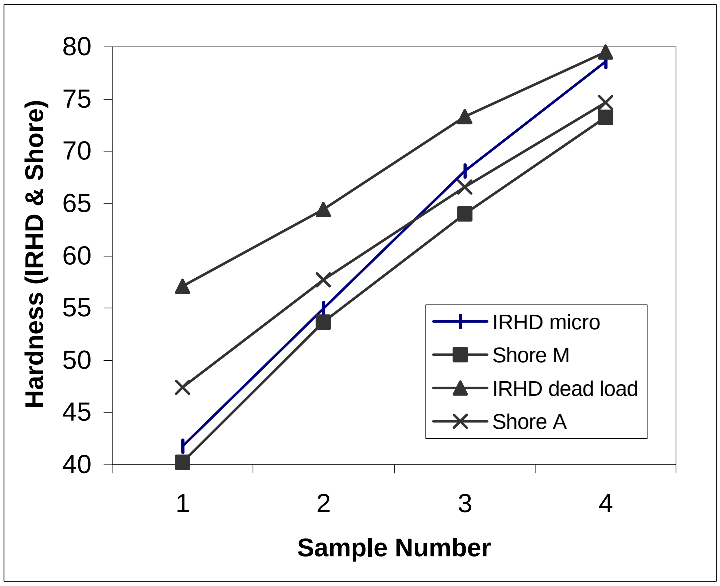

Fig. 1. – Testing 2mm thick samples on micro and macro instruments

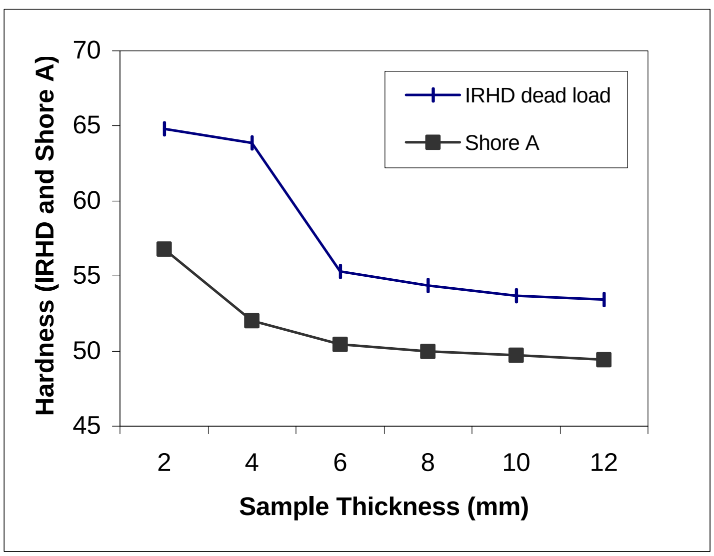

Fig. 2. – Decreasing hardness with increasing sample thickness

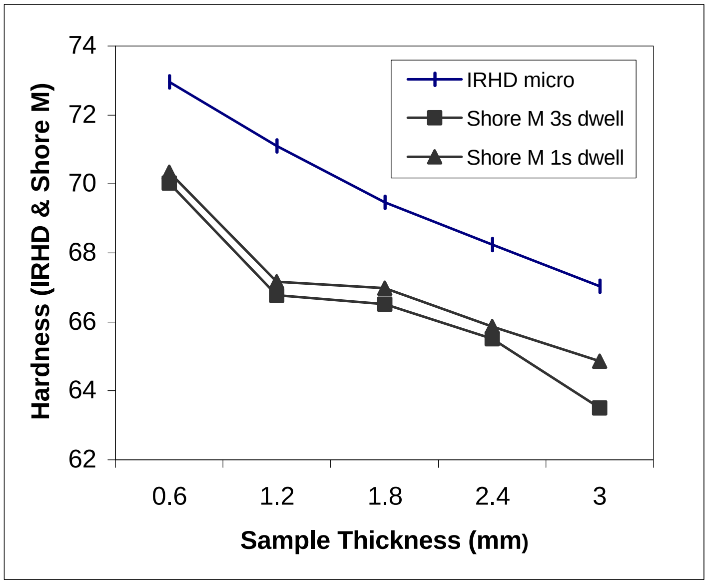

Fig. 3. – Increasing the thickness of a neoprene sample

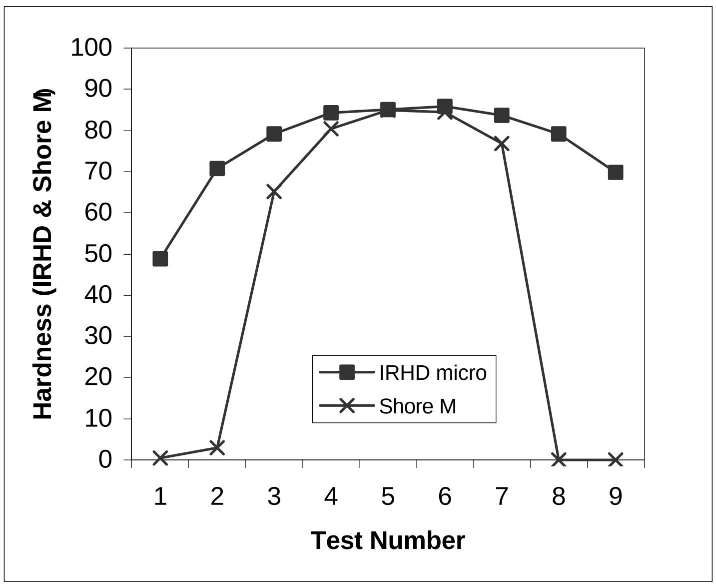

Fig. 4. – Differences in testing an O Ring of core diameter 2.5mm on IRHD micro and Shore M