EXPERT KNOWLEDGE
TEST PROCEDURES
OF ELASTOMER COMPONENTS

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1915 - 2015: 100 Years of Shore A Hardness Testing

A historical review of the development and research of the Shore A measuring method with reference to today's testing practice

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*„Shore durometer hardness, although perhaps
the least precisely defined of all hardness standards,
has been nearer than most to being accepted
as a universal standard."*[1]

A.L. SODEN:
A Practical Manual of Rubber Hardness Testing
London, **1952**

It is interesting that modern literature on elastomer testing contains little on the origins and background of the important basic test types, such as tensile testing, hot-air aging,

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[1] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons, Ltd., London, 1952, S.9

compression set or hardness testing. How have the respective methods developed? Why did one method prevail and why did the other one fall into oblivion?

Dealing with the history of technical test procedures is not only interesting, it also serves in today's testing, granting better and deeper understanding as well as better implementation of already long established test procedures. The following article is intended to make a small contribution in this direction for perhaps the most popular test method in the rubber industry, the Shore A hardness test.

1915 is considered the official year of introduction of the Shore A test method. This article is published in celebration of this 100th anniversary; it includes the following topics: general history of hardness testing of materials, special features of hardness testing of polymers, different principles of hardness measurement on elastomers, introduction to the formerly important distinction between hardness and softness, 2015: 100 years of Shore A hardness testers and presentation of their further developments, explanation of the mode of operation of the early Shore A durometers, advantages, disadvantages, and criticisms of the test method, presentation of important international standards on Shore A hardness, comparability with other hardness test methods and conclusion of the series with recommendations for today's test practice.

1. The History of Hardness Testing

In ancient times, the concept of hardness is known as a property of materials. The term "durometer", which is commonly used in English for Shore A hardness testers, contains the Latin "durus" (= hard), a device for measuring hardness.

In order to ensure the function of iron products, hardness testing has always been of interest. Toward the end of the Middle Ages, mineralogy gave a real boost to hardness testing. The so-called scratch hardness scale by Friedrich Mohs (1773-1839), which was based on the experience that hard materials scratch softer ones, is particularly worth mentioning here. Mohs assembled 10 minerals in an ascending order of increasing hardness. The Mohs' hardness is determined by looking for the two adjacent reference materials that only scratch or no longer scratch the body to be examined.

With industrialization in the 19th century, the demand for hardness testing methods for metals became increasingly stronger. They were important to ensure a consistent quality. After 1870, the first dynamic hardness testing methods were developed. Uchatius dropped a chisel from a defined height onto a metal.[2]

In 1900 the Swede Johan August Brinell (1849-1925) presented the Ball Impression Test named after him at the Paris World Exhibition. A ball is pressed into the material and the measured diameter is used to calculate the indentation surface. The Brinell hardness is then the ratio of the test force applied to the permanent indentation surface.

Around 1905[3] Martens (1850-1914) developed the so-called indentation principle. Not only was the impression of a test ball measured, but the penetration depth and test force were also

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[2] Vgl. HERRMANN, Konrad: Härteprüfung an Metallen und Kunststoffen – Grundlagen und Überblick zu modernen Verfahren, Expert-Verlag, Renningen, ²2014, S.1f.

[3] Vgl. https://www.ptb.de/cms/ptb/fachabteilungen/abt5/fb-51/ag-511/haerte-und-haertepruefverfahren.html

recorded simultaneously. This method allowed more conclusions to be drawn about the material than just its plastic behavior.

The name Albert Shore first appeared to a wider public in 1907. In the same year, the "Shore Scleroscope" (Fig.1 and 2) was introduced (which was developed in 1906[4] and patented in 1910). A hammer with a diamond tip was dropped on the workpiece to be tested. The hardness could be classified by the rebound height.

Fig. 1: Presentation of a Shore scleroscope with a vertical scale from an early company brochure of "The Shore Instrument & Mfg. Co. Inc."[5] A worker determines the hardness of a metal shaft.

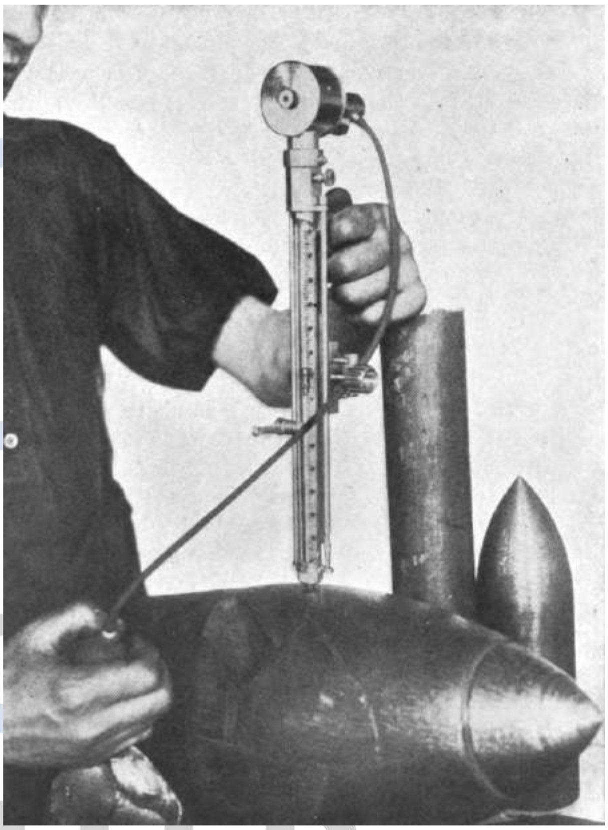

Fig. 2: A Shore scleroscope with a vertical scale from 1910 shown in a book by Albert F. Shore regarding his scleroscope.[6] A worker determines the hardness of a bullet.

(Webseite abgerufen am 20.07.2015)

[4] SHORE, Albert F. : The Shore scleroscope for measuring hardness of metals, Shore instrument & mfg. Co., New York, 1910, S.3 Buch digitalisiert online verfügbar: http://babel.hathitrust.org/cgi/pt?id=hvd.32044091972851;view=1up;seq=23

[5] The Shore Instrument & Mfg. Co. Inc.: Bulletin R4: The durometer and elastometer 20th year: an international standard of measurement for hardness and elasticity of rubber, Jamaica, N.Y., Jan.1934, S.4 (Abdruckerlaubnis der Fotografie mit freundlicher Genehmigung des Hagley Museum and Library, USA)

[6] SHORE, Albert F. : The Shore scleroscope for measuring hardness of metals, Shore instrument & mfg. Co., New York, 1910, S.17
Buch digitalisiert online verfügbar: http://babel.hathitrust.org/cgi/pt?id=hvd.32044091972851;view=1up;seq=23

Despite the fact that this was a pure metal test instrument, it already has some very practice-oriented properties which were later also used in the Shore durometer to determine the elastomer hardness.

The hardness scale of the scleroscope was divided into 100 degrees of hardness, where the value 100 stood for a martensitic carbon-rich steel, so, as in the Shore A elastomer test, the number 100 represented the hardest value. The scleroscope was portable, relatively inexpensive compared to other hardness testers and could be easily operated by a semi-skilled worker.[7] Moreover, this test method was many times faster than comparable hardness test methods at the time, and specimens of any size could be tested.[8] All these properties also characterized the first Shore A hardness testers for elastomers.

2. The Proportion of Plastic and Elastic Components of a Material

If indentation tests are carried out to determine the hardness, three different cases can be distinguished:

"Either elastic deformations predominantly occur under the selected conditions of the single-point test or the permanent deformations are predominant, however, the elastic deformations are negligible. The third case is the simultaneous occurrence of elastic and plastic deformation of similar magnitude".[9]

The first case is typical for elastomers. The decisive factor for determining hardness is the elastic restoring force. Therefore, there is a strong dependence between elastic characteristic values and hardness values. Since the indenter usually leaves a hardly visible impression when measuring Shore hardness, the deformation path must be measured under load. The hardness of an elastomer is strongly influenced by the rubber compound, especially by the fillers, their density, and the cross-linking system. Elastomers do not have a linear stress-strain diagram in the tensile test, which means that there is no clear E-modulus as with metals. The modulus of elasticity of rubber changes with increasing elongation.

The second case, in which the plastic deformation is significantly higher than the elastic deformation, usually occurs with metals. "Here, the resulting deformation can be measured after the load has been removed. It is well known that there is a certain relationship between this hardness and the tensile strength of iron. Of course, such a correlation cannot be expected if the indentation test essentially covers the elastic area, as it is the case with rubber".[10] In the field of metallic materials, a very clear distinction is also made between hardness and rigidity. "In the case of metals, the term hardness is obviously associated with the plastic property. The term of rigidity, on the other hand, describes the elastic behavior of the material. In engineering, the modulus of elasticity E is used as the physical measure for rigidity and the technical

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[7] Vgl. https://sizes.com/units/shore_scleroscope.htm (Webseite abgerufen am 20.07.2015)

[8] The Shore Instrument & Mfg. Co. Inc.: Bulletin R4: The durometer and elastometer 20th year: an international standard of measurement for hardness and elasticity of rubber, Jamaica, N.Y., Jan.1934, S.4

[9] translated from SPÄTH, Wilhelm: Beiträge zur Technologie der Hochpolymeren – Gummi und Kunststoffe, A.W. Gentner Verlag, Stuttgart, 1956, S.123

[10] translated from Ebd., S.123f.

[dimensionless] measures are introduced for hardness"[11] (e.g. hardness according to Rockwell, Brinell etc.).
The third case, a relatively balanced ratio of elastic and plastic components, usually occurs with plastics. Understandably, this makes the definition and determination of hardness difficult. For this reason, both hardness test methods exist side by side when testing plastics, as in the rubber industry (measurement of the penetration depth) and in the metal industry (measurement of the impression after removal of the force).

3. Different Principles of Hardness Measurement on Elastomers

The well-known bon mot of metal material testers: "When we measure hardness, we always leave a good impression", does not apply to rubber materials.
"With elastomers, it is not possible to measure permanent deformation after removal of an indenter, as is the case with metals. The extremely high elasticity of rubber, i.e. its spontaneous re-deformation after loading, is probably one of the most important properties of this material."[12]
Nevertheless, an attempt was made in the 1940s to develop a standardized indentation test method for various materials (metals, elastomers, plastics). In 1940 KUNTZE recommends the following in the trade journal "Kautschuk" (rubber):[13] A "tester in which the indenter is a pyramid and in which the spring has been calibrated to pressure in grams to give a reading representing the indentation resistance in kg/mm^2."[14] However, such attempts of a standardization could not be established.

At the turn of the last century, two important different principles for measuring the hardness of elastomers were developed, which were improved and refined over the decades and are still used today:

3.1 Hardness Testers with a Load Weight

The indenter is usually preloaded with a small weight to ensure contact with the specimen. Then, the actual load weight is added. The hardness value is read off after a specified test period (today, usually longer than with spring-loaded devices). With this principle, the hardness value consists of the penetration of the indenter due to plastic flow and a second part caused

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[11] translated from SPONAGEL, S. ; UNGER, J.; SPIES, K.H.: Härtebegriff im Zusammenhang mit Vernetzung, Bruchdehnung und Dauerfestigkeit eines Elastomers in: KGK Kautschuk Gummi Kunststoffe, 56.Jg., Nr.11, 2003, S.608

[12] Of course, elastomers also have plastically deformable elements, but these are so small with the deformations (at 23°C) and forces caused by the indenter of the hardness measurement that they cannot be measured easily and reproducibly.
A test method for measuring the permanent deformation after loading is the compression set test at elevated temperatures. Here, however, the primary concern is not plastic deformation, but the breakage of old network structures and new cross-linking in the pressed position.

[13] KUNTZE, W.*: Einheitliche Eindruckhärteprüfung für Gummi, Kunststoffe und Metalle in:* Kautschuk, 16, 1940, S. 83-87

[14] BREUERS, W. und LUTTROPP, H.: Buna – Herstellung Prüfung Eigenschaften, VEB Verlag Technik, Berlin, 1954, S.225

by elastic deformation. The test devices activated by spring force presented in the following more or less represent only the elastic indentation.[15]

In the middle of the 20th century, there was a large number of test instruments working according to this principle (e.g. GB: Wallace Gauge, R.A.B.R.M. Pattern Gauge, Admirality Rubber Meter, USA: Tinius Olsen Gauge, D: DVM softness tester from L.Schopper in Leipzig (see Fig. 3), Zwick "Zet 8", F: Lhomme & Argy). Today, the IRHD method with all its sub-variants (e.g. micro-hardness) has established itself in everyday testing. Only special industries still use special test methods, so the Pusey & Jones Plastometer is used to determine the hardness of rubber rolls in the paper industry.

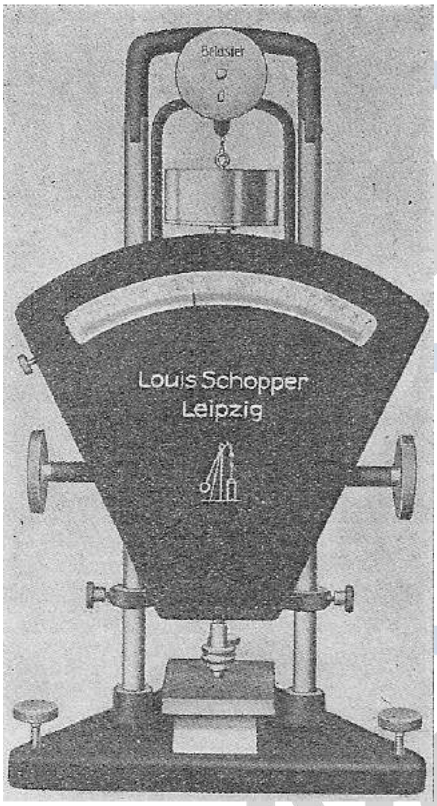

Fig. 3: A DVM softness tester with load weight (1kg, above the display scale) by Louis Schopper, Leipzig, at 1940[16] - a forerunner of today's IRHD test equipment**.**

3.2 Hardness Testers with Spring Force (Short: Spring Pressure Testers)

The test force is transferred to the indenter by means of a spring.

Albert Shore's durometer is undoubtedly the most prominent instrument here. However, there were also variants of other manufacturers, partly with other indenters as used by Shore (e.g. **GB**: Wallace Pocket Meter, **USA**: Adams Densimeter, Firestone Penetrometer, Rex Gauge, Dunlop Hardness Gauge).

3.3 Other Alternative Hardness Testing Methods for Elastomers

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[15] CARPENTER, Arthur W.: Physical Testing and Specifications in: DAVIS, Carroll C.: The Chemistry and Technology of Rubber, Reinhold Publishing Corporation, New York, 1937, S.812

[16] KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.82

In older literature, the third method is mentioned as the so-called "Herbert Pendulum"[17]. This hardness testing method is not based on the penetration principle, but is usually used to measure the influence of the hardness of a material on the oscillation time of a moving pendulum. The pendulum is mounted with a hemisphere on the material to be tested, brought into a pre-defined initial position and then released. The system dates back to the 1920s, but has not become widely accepted in the elastomer industry, as SCOTT already noted[18] in 1955. Today, this method is occasionally used with modifications in the hardness testing of metals[19].

Another interesting approach to hardness measurement was patented[20] in 1949 by BUIST and KENNEDY, employees of the British ICI. Their invention describes an apparatus that allows an indenter to intrude a predetermined distance into the specimen by measuring the force required with the aid of a hydraulic system. The force applied is then a measure of the hardness of the material. Such a kind of testing device was also only intended as a table-top device. It was not the load weight that was kept constant as before, but the penetration distance of the indenter. JUVE notes that this device can also be used to measure extremely soft elastomers without encountering the effect of a limited penetration distance.[21]
With the classic hardness testers (spring principle or constant load weight), the hard steel base falsifies the result more strongly when measuring soft elastomers than when measuring hard elastomers with test specimens of the same height. This invention by BUIST and KENNEDY could greatly reduce this undesirable effect, which would then depend only on the specimen thickness and no longer on the hardness itself.
In 1997 KUCJERSKII and KAPOROVSKII[22] took up the idea of hardness measurement with constant deformation again. With this method it is possible, according to their results, to make more appropriate statements about the real stiffness of a material. However, this test method could by no means replace the established hardness test methods in the elastomer industry.

The Shore scleroscope described above is a dynamic hardness testing method for metals, whereby the equivalent in the rubber area would be the rebound elasticity test. However, this method is not used here to determine the hardness, since e.g. elastomers of the same Shore hardness can have very different rebound elasticities. The rebound elasticity of elastomers allows a conclusion to be drawn about the hysteresis loss under sudden stress. It is, therefore, primarily a measure of the purely elastic behavior of the material, while the hardness test

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[17] Weblink zur einer frühen Beschreibung der Funktionsweise des Herbert Pendulums in: FLIGHT – The Aircraft Engineer and Airships, 13.09.1923: http://www.flightglobal.com/pdfarchive/view/1923/1923%20-%200550.html (Webseite abgerufen am 31.07.2015)

[18] SCOTT, J.R.: Rubber Hardness Testing in: Rubber Age, New York, Vol. 77, No.4, July, 1955, S.544

[19] SUZUKI, R., KABURAGI, T., MATSUBARA, M., TASHIRO, T. und KOYAMA, T. (2015), Hardness Measurement for Metals Using Lightweight Herbert Pendulum Hardness Tester With Cylindrical Indenter. In: Experimental Techniques, Feb. 2015, doi: 10.1111/ext.12121 http://onlinelibrary.wiley.com/doi/10.1111/ext.12121/abstract (Webseite abgerufen am 22.09.2015)

[20] BUIST, J. M. und KENNEDY, R. L.: Apparatus for Measuring the Hardness of Rubber and similar Materials, Britisches Patent GB617465 (a) – 1949-02-07 (Weblink zum Patent (abgerufen am 01.09.2015): http://worldwide.espacenet.com/publicationDetails/originalDocument?CC=GB&NR=617465A&KC=A&FT=D&ND=3&date=19490207&DB=worldwide.espacenet.com&locale=de_EP)

[21] JUVE, A.E.: Physical Test Methods and Polymer Evaluation (chapter 12) in: WHITBY, G.S. et al. (Hrsg.): Synthetic Rubber, Jon Wiley & Sons, Inc. New York, 1954, S.445

[22] KUCHERSKII, A.M. und KAPOROVSKII, B.M.: A promising method for measuring hardness of rubbers in: Polymer Testing, Vol.16, Issue 5, October 1997, S.481-490

methods commonly used today also cover the plastic components of an elastomer. (Effect of the decrease in hardness with longer test times).

There are also correlations between hardness and abrasion resistance for certain materials. However, due to the many variables involved in abrasion testing (surface, test speed, friction-lubrication ratio, etc.), it is not useful to determine the hardness of a material using such a method.[23]

Other hardness testing methods, such as hardness testing by scribing or cutting, are not used for elastomers. Due to the elastic recovery of this type of material, such defined injuries are difficult or non-reproducible to measure. In addition, the cutting and scribing properties of an elastomer are also more or less strongly influenced by the fillers.

4. Hardness vs. Softness

Until the 1950s in Germany, the term "softness" was propagated and used in parallel with the term hardness. However, the term "softness" has disappeared from testing practice today, but is worthwhile to deal with the interesting train of thought behind it, since it can contribute to a deeper understanding of hardness testing.
The DIN DVM standard[24] for hardness testing with a load weight, published in June 1938, reads "Testing rubber - Determining the softness of soft rubber".
SPÄTH defines it as follows in 1940: "The softness of a material is... the resilience which the test specimen shows when another (harder) [= indenter] penetrates... At first glance, it may seem strange to speak of the softness of a material instead of hardness. After all, today's language uses the property words "soft" and "hard" in a completely equivalent sense. One can say that material A is harder than material B or that material B is softer than material A. However, this complete equality of the two expressions "hard" and "soft" was not followed by language creation in the formation of corresponding nouns. One speaks only of hardness, and this term has also been generally used in scientific considerations; therefore, one does not speak of the inverse value, i.e. the softness. This one-sided development is actually very surprising because the word "soft" should have been formed from the daily handling of the materials instead. Sensual perception primarily refers to the size of the deformation that can be achieved by external influences, i.e. to the softness and not to the hardness“.[25]
With the DVM softness tester the result was given in 1/100mm penetration depth of the indenter (sphere Ø = 10mm) with a load of 1000g (+ 50g preload) after 10 seconds. This means that with a soft material a large penetration depth was obtained, and, therefore, a high result value.[26] This result value was called "softness number", which could also be greater than 100.

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[23] Vgl. TOBOLSKI, Ed: Back To Basics: Hardness Testing in: QUALITY MAGAZINE, April 2007, Weblink: http://www.qualitymag.com/articles/89348-back-to-basics-hardness-testing (abgerufen am 12.08.2015)

[24] DVM: Deutscher Verband für die Materialprüfungen der Technik, Webseite der heutigen Nachfolgeorganisation: www.dvm-berlin.de

[25] SPÄTH, Wilhelm: Physik und Technik der Härte und Weiche, Verlag von Julius Springer, Berlin, 1940, S.24f.

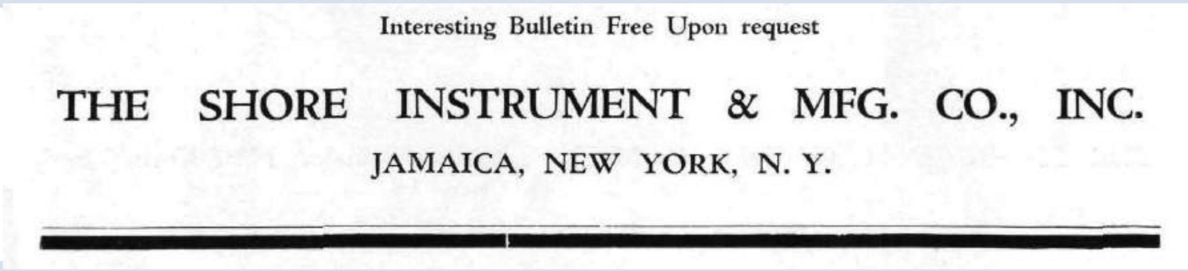
[26] This principle "soft material => high result value" also existed with many other foreign hardness testers of the 1930s (z.B. Hardness Gauge R.A.B.R.M., Hardness Gauge A.S.T.M., Penetrometer, Firestone Tire & Rubber Co.

In ShA hardness measurement, it is exactly the other way round: A soft material results in a low measured value. A ShA hardness of 40 corresponded approximately to a DVM softness number of 90.[27] In this respect, this different designation made sense because the same material now had a high hardness value (according to ShA) or a low softness number (according to DIN-DVM 3503, June 1938).

Presumably, this distinction of concepts and thinking in inversions has led to confusion in everyday professional life, despite its accuracy. In the IRHD method, for example, the penetration depth was converted to a scale from 0 to 100 with 100 representing the hardest value as it is in the ShA method.

5. Introduction of the Durometer (Type "A") 100 Years Ago and Further Developments in the Early Phase

1915[28] is considered the official year of the introduction of the Type A durometer by Albert Ferdinand Shore.



Interesting Bulletin Free Upon request

THE SHORE INSTRUMENT & MFG. CO., INC.

JAMAICA, NEW YORK, N. Y.

Fig. 4: From an early advertising brochure , the Bulletin R4[29]

5.1 Early US Patents on Pocket Testers for Elastomers

However, a very similar invention could be proven by patent searches. William F. Shore had already applied for a patent in 1911 and patented it on 29 October 1912 under the number 1,042,721. William was probably Albert's brother.[30] This document presents a pocket-sized round hardness tester that anticipates many of the features of the later round durometer ("round style"). The patent drawing (Fig. 5) even shows the truncated cone indenter and the

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u.v.m.). This principle has been retained in the Pusey&Jones test method (ISO 7267-3, ASTM D 531) used up to now.

[27] Vgl. BREUERS, W. und LUTTROPP, H.: Buna – Herstellung – Prüfung – Eigenschaften, VEB Verlag Technik Berlin, 1954, S.228, Bild 128

[28] Shore® An Instron Company (Hrsg.): Shore® Durometers (Werbesprospekt), Instron Corporation, Canton, MA, 2004, S.8

[29] The Shore Instrument & Mfg. Co. Inc.: Bulletin R4: The durometer and elastometer 20th year: an international standard of measurement for hardness and elasticity of rubber, Jamaica, N.Y., Jan.1934, S.4 (Reprint permission of the photograph courtesy of the Hagley Museum and Library, USA)

[30] E-Mail of 12.01.2015 from Alan Garrett, (former Commercial Director of the British Hampden Test Equipment), who personally knew the last General Manager (approx. 1970-1996) of SHORE Mfg. Co., Bill Galbraith. There is also a joint US patent (US 1,768,639 dated July 1, 1930) Albert F. and William F. Shore, which supports this thesis.

use of a more pointed indenter for harder materials is suggested. The hardness scale already goes from 0 to 100, but the movement of the pointer is from 100 to 0. The most significant difference to the durometer introduced in 1915 is the use of a helical compression spring instead of the leaf springs that were later used. This invention was especially designed for testing rubber, as described at the beginning of the patent. In addition, it was already recognized that not only the hardness but also other properties of the material could be measured, such as resilience and elasticity.

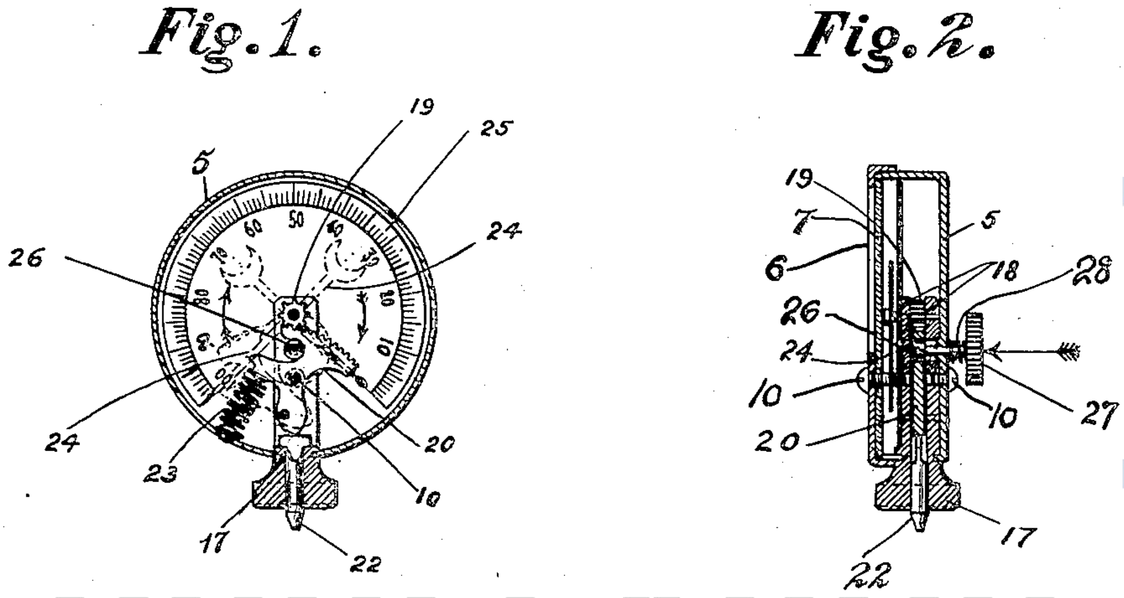

Fig. 5: Drawing from US patent 1,042,721 ("Gage") dated 29.10.1912 by William F. Shore: The hardness tester shown here already shows many properties of the later round durometers: Round scale from 0 to 100 divided into single steps (25), Indenter as truncated cone (22), widened foot for plane-parallel positioning (17), press force of the Indenter spring activated (23)

Why the introduction of the "quadrant type"[31] durometer (see chapter 5.3) with a much more inaccurate reading scale occurred in 1915 cannot be explained anymore today. Perhaps Albert wanted to circumvent his brother's patent. When the round durometer was introduced in 1944, it had already expired.

However, after reviewing this document, it becomes difficult to describe Albert F. Shore as the sole inventor of the Shore durometer.

The "quadrant type" and the round durometer were very popular. By 1957, 15,000 "quadrant type" durometers and 9,000 round durometers had already been sold, of which 80 or 90% were still in use[32] in 1957, depending on the type. This high degree of utilization also indicates the good and robust quality of the instruments.

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[31] Occasionally, the term "quadrant device" can be found in historical German-language specialist literature, e.g. in: HÄNDLER, F. und KAINRADL, P.: IR-Härte, Mikro-Härte und Shore-Härte, Lecture Conference of the German Rubber Society, 4-8 October 1960 in West Berlin, p.16

[32] JUVE, A.E.: Recent Developments in Hardness Testing in: American Chemical Society (Hrsg.): Rubber chemistry and technology, Lancaster, Pa, Heft 2, 1957, S.367

In the period that followed, devices were developed for softer and harder materials, whereby the hardness and, partly, the contact force increase with the letter ascending in the alphabet (e.g. Shore D for plastics, see Fig. 6). This article deals only with the most widely used type. "A". Albert F. and William F. Shore jointly applied for a patent in 1924 for various indenter geometries and finally it was patented in 1930 (US1,768,639).

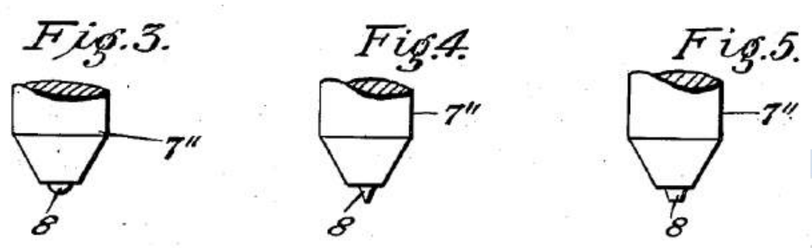

Fig. 6: Drawing from US patent 1,768,139 ("Gauge") dated 01.07.1930 by Albert F. and William F. Shore: In addition to the patenting of a hardness tester of the round type, the adjacent indenter types were also shown in the patent drawing.

5.2 Albert Ferdinand Shore - His Life and Environment

Albert Ferdinand Shore was born in 1876 and died in 1936. He was the founder of the company "The Shore Instrument & Mfg. Co. Inc.", which was based in Jamaica, New York. Shore's son, Fred, continued the business after his father's death.[33]

Albert Shore has published very little. A book about the scleroscope[34] (although his sole authorship is not clear) and an essay in a conference transcript of a "Regional Meeting" of ASTM in Cleveland[35] has been preserved. On the other hand, over 30 patents of Albert F. Shore and Albert Ferdinand Shore from New York in the period from 1899 to 1934 (both priority dates) can be proven. The last publication of a patent with him as inventor took place in 1936.[36]

Albert F. Shore

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[33] Vgl. GARRATT, Alan F.: The History and Origins of the Durometer, online veröffentlicht: http://shore-durometer-history.blogspot.de/ (Zugriff auf Webseite am 21.07.2015)

[34] SHORE, Albert F. : The Shore scleroscope for measuring hardness of metals, Shore instrument & mfg. Co., New York, 1910, 64 Seiten, illustriert
Buch digitalisiert online verfügbar: http://babel.hathitrust.org/cgi/pt?id=hvd.32044091972851;view=1up;seq=23

[35] SHORE, Albert, F.: Discussion on Shock and Vibration Properties in: AMERICAN SOCIETY FOR TESTING MATERIALS (Hrsg.): Symposium on Rubber held at Cleveland Regional Meeting 1932, Philadelphia, 1932, S.93-97

[36] Since the signatures of the inventor on the patent drawings are very similar, it can be assumed that all patents under the name Albert (Ferdinand) Shore are the same inventor. In addition, all priority data fall within his active working life.

Fig. 7: Albert Ferdinand Shore (1876 - 1936), inventor of the Shore A durometer [37] [38]

Albert Ferdinand Shore seems to have been a technically interested and educated person. In addition to patents for hardness testers, there are also patents for optical problems (e.g. US1590448: 1926-06-29: Photographic camera and lens), for areas in vehicle construction (e.g. US1054992: 1913-03-04: Locomotive driving wheel or US1520483: 1924-12-23: Spring support for vehicles) and military technology (e.g. US1089161: 1914-03-03: Projectiles). In one patent each of Albert F. Shore appears an additional Charles P. Shore and a William F. Shore, who also belonged to his family and were presumably his brothers.[39]

5.3 Products from the First Decades of Shore Instruments Mfg.&Co., Introduction of the Round Durometer in 1944

The oldest company brochures to be found in public libraries today are from the 1930s. In the form of publications, there were partly scientific professional articles, such as, the "Bulletin R-4", as well as advertised products. The following pictures (Figs. 8-10) are taken from such "bulletins".

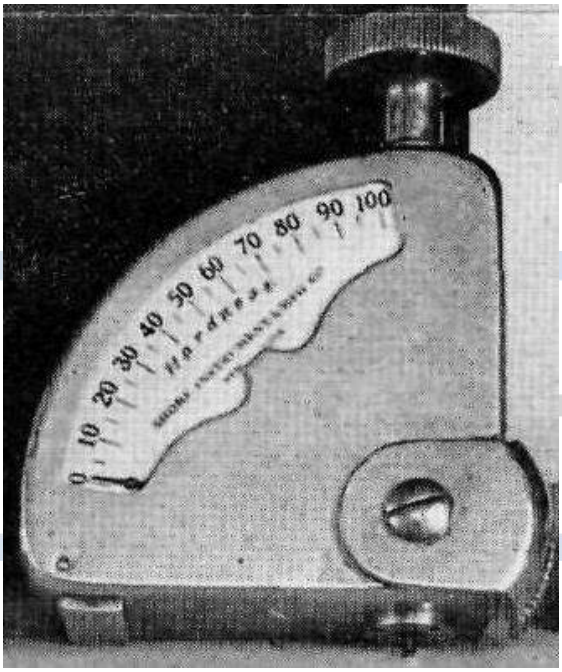

Fig. 8: An early ShA hardness tester ("quadrant type") from "The Shore Instrument & Mfg. Co. Inc.", about 1935[40]

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[37] Quelle der Fotografie: GARRATT, Alan F.: The History and Origins of the Durometer, online veröffentlicht: http://shore-durometer-history.blogspot.de/

[38] The signature Albert F. Shores was taken from: US-Patent 1,770,045 dated July 08, 1930: Apparatus for the Measuring the Hardness of Materials, Inventors: Albert F. and Charles P. Shore, S.1 (Patent Drawing)

[39] E-Mail of 01/12/2015 from Alan Garrett, (former Commercial Director of British Hampden Test Equipment), who personally knew the last General Manager (approx. 1970-1996) of SHORE Mfg. Co., Bill Galbraith.

[40] The Shore Instrument & Mfg. Co. Inc.: Bulletin R4: The durometer and elastometer 20th year: an international standard of measurement for hardness and elasticity of rubber, Jamaica, N.Y., Jan.1934, S.3 (Reprint permission of the photograph courtesy of the Hagley Museum and Library, USA)

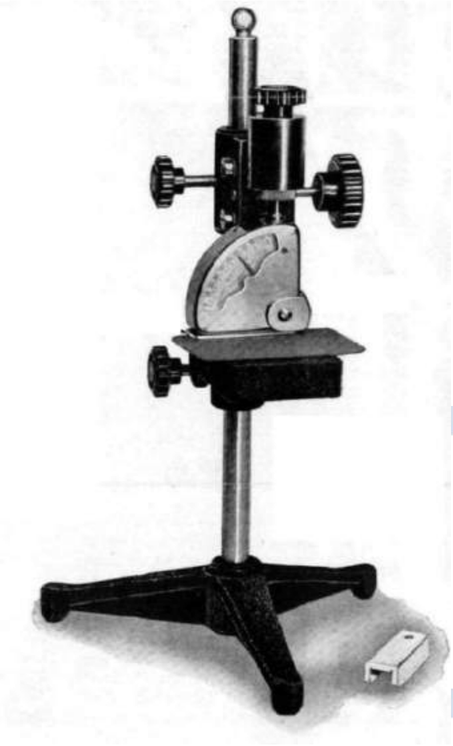

Fig. 9: Soon the problem of the large operator influence during the ShA test was recognized. In order to reduce this influencing factor, a stand was offered as early as 1935.[41]

Not quite 30 years after the introduction of the first ShA hardness tester, in 1944, "The Shore Instrument & MFG Co." released a round tester with a much more accurate reading scale.

Fig. 10: Presentation of the round Shore A measuring instrument of Shore Instrument &MFG Co., Jamaica, N.Y. with stand (introduced 1944). It received the designation "A2-Durometer".[42] With the rotary knob on the right above the durometer, it could be moved up or down. At the beginning of the 1950s, a stand from ZWICK & Co KG was already available, which pressed the durometer against the sample

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[41] Ebd., S.1 (Reprint permission of the photograph courtesy of the Hagley Museum and Library, USA)

[42] The Shore Instrument & Mfg. Co. Inc.: Bulletin R6: A2-Durometer (adopted 1944), Jamaica, N.Y., ca. 1945, S.1 (Reprint permission of the photograph courtesy of the Hagley Museum and Library, USA)

with the aid of a load weight. This led to a better repeatability of the contact force for different operators. [43]

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[43] Vgl. SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S.39

Fig. 11: A later example of a Shore D handheld tester ("quadrant type") with leather case, (permission to reproduce courtesy of "Toronto Surplus & Scientific", Canada)

In 1995, after several changes of ownership, INSTRON acquired the company, including the rights for the designation "Shore Durometer".[44] However, Instron no longer manufactures durometers and the website www.shoreinstruments.com is no longer active.

5.4 The Production of ShA Pocket Testers in Germany

Quite soon Shore hardness testers were also manufactured in Germany in great variety. In 1942 KLUCKOW[45] already described three Shore hardness testers from German production, which are shown in Fig. 12-14. All devices are still variations of the original "quadrant type" style of the US-American company Shore. The outer dimensions correspond approximately to a quarter circle. It is also evident that the reading scale is divided into steps of 5 ShA degrees of hardness. It can be assumed that the ±5 ShA tolerance that is still common today for the indication of hardness values can still be traced back to this rough division of the initial time. Although, today many elastomer products can also be produced in a hardness window of ±3 ShA.

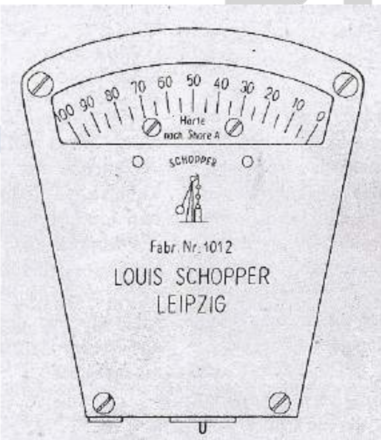

Fig. 12: Schematic drawing of a Shore A hardness tester by Louis Schopper, Leipzig, ca. 1940[46]

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[44] Vgl. GARRATT, Alan F.: The History and Origins of the Durometer, online veröffentlicht: http://shore-durometer-history.blogspot.de/ (Website accessed 21.07.2015)

[45] KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.82

[46] Ebd., S.82

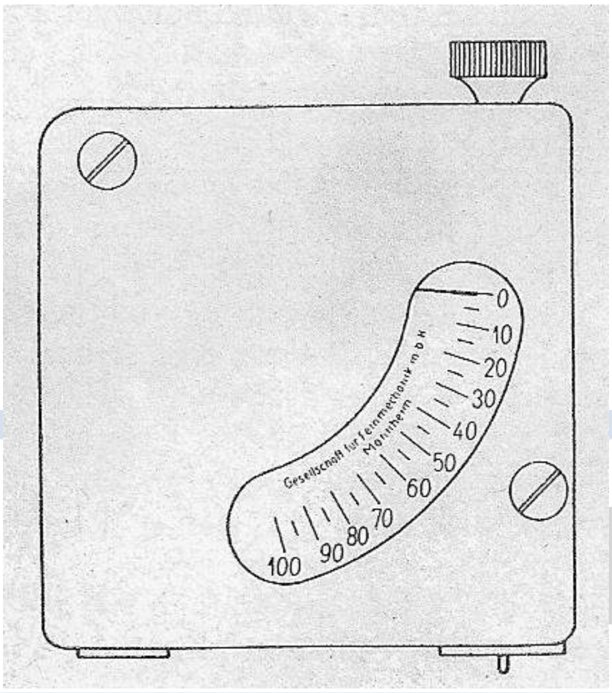

Fig. 13: Schematic drawing of a Shore A hardness tester of the Gesellschaft für Feinmechanik m.b.H., Mannheim, around 1940[47]. A very similar device in this square. Form was also available from "Otto Wolpert-Werke G.m.b.H. Ludwigshafen a.Rh." [48] around 1950.

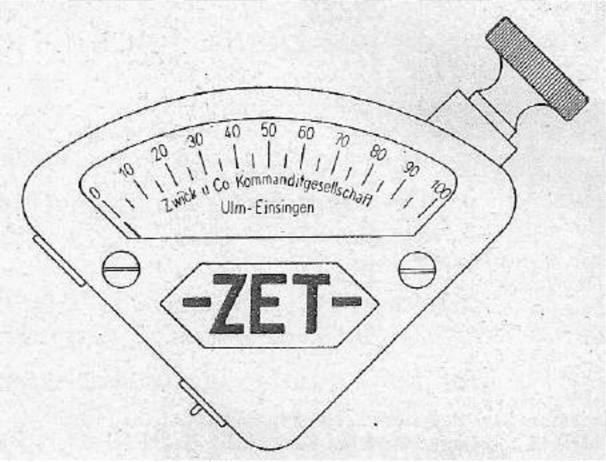

Fig. 14: Schematic drawing of a Shore A hardness tester of Zwick u.Co. Kommanditgesellschaft, Ulm-Einsingen, around 1940[49]

After 1945, pocket testers were continued to be manufactured which still had the classic 5ShA classification. Fig. 15 shows a handheld tester from the company Karl Frank, which is strongly reminiscent of the Schopper tester from the 1940s. After the Second World War, the company Louis Schopper merged in East Germany into the "VEB Werkstoffprüfmaschinen Leipzig".[50]

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[47] Ebd., S.82

[48] MAU, K.: Aus der Praxis des Gummifachwerkers, Berliner Union, Stuttgart, ²1951, S.316

[49] KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.82

[50] http://www.werkstoffpruefmaschinen-leipzig.de/4507.html (Website accessed on 22.09.2015)

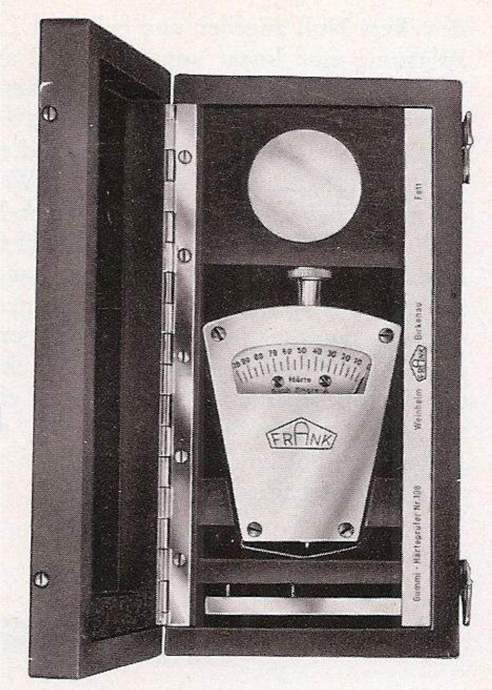

Fig. 15: ShA hardness tester from Karl Frank, Weinheim Birkenau, Germany, 1955[51]

Fig. 16: An early pocket tester HP from Bareiss, still very similar to the original "quadrant style" of an A.F. Shore. (Photo: Bareiss Prüfgerätebau GmbH, www.bareiss.de)

Later, round durometer pocket testers (Fig. 17) were also manufactured in Germany, among others by the company Bareiss from Oberdischingen, which was founded in 1954.

Fig. 17: A historical round pocket tester HP from Bareiss, already with a division of the degrees of hardness into single steps (Photo: Bareiss Prüfgeräte-bau GmbH, www.bareiss.de)

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[51] FRANK, K. (Hrsg.): Prüfungsbuch für Kautschuk und Kunststoffe, Berliner Union, Stuttgart, 1955, S.37

6. The Functionality of the Original Durometer ("Quadrant Type") and the First Round Version of the Pocket Tester

The following **Fig. 18** shows a Shore Durometer in the classic "quadrant type" form, open at the back.

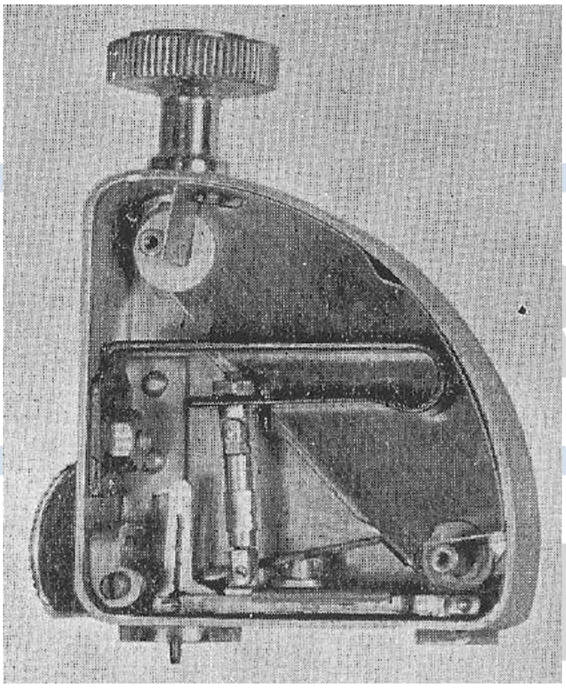

Fig. 18: Mechanism of the original Shore A hardness tester ("quadrant type"), view on the opened back side. [52]

The function of this classical durometer ("quadrant type") is quickly explained with the help of the following Fig. 19:[53]
If the test device with its pressure foot and projecting indenter is placed on the elastomer specimen, the indenter is pressed upwards. This also causes the lever (2), which is mounted in a pivot (3), to move upwards. The frame (4) rotates the wheel (5) to which the pointer (6) is attached. This then indicates the corresponding hardness on the scale as the penetration depth.
The leaf spring (8) transmits its force to the carriage (9) via a connecting arm (7).
Four elements could be adjusted in this classic durometer type:

- The tip of the penetrator protruding from the contact surface
- The length of the connecting arm (7)
- Change the angle of the connecting arm (7) by moving the carriage (9) on the lever (2)
- The position of the spring in relation to the housing

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[52] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 35
[53] A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 34

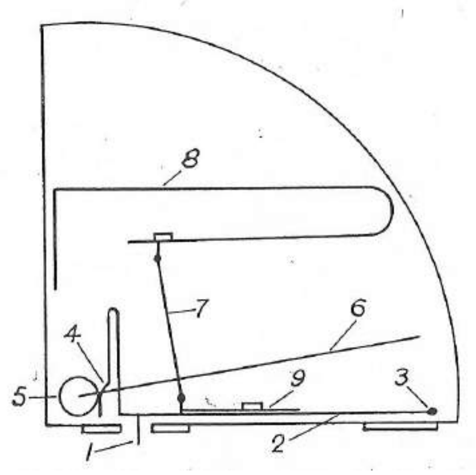

Fig. 19: Schematic sketch of the inner workings of the Shore A hardness tester ("quadrant type")[54]

If you take a closer look at the standards for ShA testing, you may wonder about some "strange" dimensions and tolerances of the indenter, its maximum travel and the contact pressures. A look at the American units solves some "mysteries". When converting the original dimensions and forces, one notices that in pre-digital times, fractions were used more than comma numbers.

Standardized Device Part (Excerpt)	**Original Values of A.F. Shore** [55]	**Conversion to SI Units** (1 inch = 25.4 mm) 1 oz. ≈ 28,35 gr. corresponds to approx. 278.11 mN)	**Standard requirements according to DIN EN ISO 868** (Issue Oct. 2003)	**Standard requirements according to ASTM D2240 - 05 (2010)**
Large Ø of the Indenter	3/64 inch	1,1906 mm	1,25 ± 0,15 mm	1,27 ± 0,12 mm (0,050 ± 0,005 inch)
Ø of the flat tip of the truncated cone	1/32 inch	0,7938 mm	0,79 ± 0,03 mm	0,79 ± 0,03 mm (0,031 ± 0,001 inch)
Contact Pressure	2 oz.	556,2 mN	550 mN ± 75 mN	0,55 N ± 0,075 N
Spring Force at 100 ShA	29 oz.	8065,2 mN	8050 mN ± 75 mN	8,05 N ± 0,075 N
Total Travel of the Indenter (= Full Deflection)	1/10 inch	2,54 mm	2,5 ± 0,04 mm	2,5 ± 0,04 mm (0,098 ± 0,002 inch)
Needle Travel per 1 Hardness ShA	1/1000 inch	0,0254 mm	0,025 mm	0,025 mm (0,001 inch)
Newton / 1 Degree of Hardness ShA			n.a. in the standard	0,075 N / 1°ShA

Tab. 1: Derivation of the dimensions or forces of a durometer, which today conform to SI units from the original US American units

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[54] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 35

[55] SHORE, Albert, F.: Discussion on Shock and Vibration Properties in: AMERICAN SOCIETY FOR TESTING MATERIALS (Hrsg.): Symposium on Rubber held at Cleveland Regional Meeting 1932, Philadelphia, 1932, S.96

In 1944, Shore Instrument & Mfg. Co. launched the first round pocket tester. SODEN[56] wrote in 1952 that this instrument had already completely replaced the previous "quadrant type" instruments of the manufacturer of the same name. Although it was bigger and heavier than its predecessor, it had become established within a few years. The reason for this was certainly the higher accuracy, since a reading in 1 ShA step was now possible. Due to the larger pressure foot, a too high contact pressure of the device by the operator was avoided, which also increased the precision. In addition, this improved device together with a tripod cost about the year 1945 just as much as its predecessor in 1934, which was $125.[57]

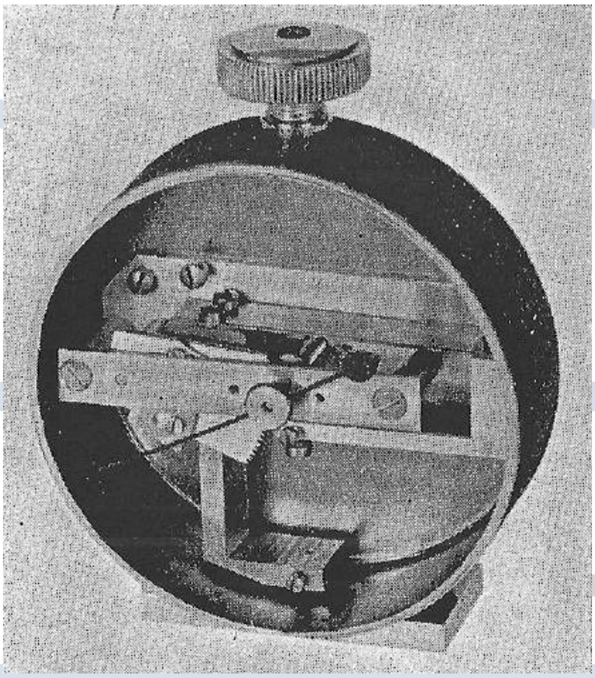

Fig. 20: Mechanism of the round Shore A hardness tester ("round style"), view onto the opened rear side [58]

The functionality of this round pocket tester (Fig. 21) is fundamentally different from the " quadrant type " used until then. A.L. SODEN describes it as follows[59]:

Two parallel leaf springs (1) are kept apart at both ends by the small metal blocks (2 and 3). The metal block (2), a spacer for the leaf springs (1), is firmly fixed to the housing. The other metal block (3) can move freely up or down. This movement is caused by the indenter (5) connected to the block (3) by a connecting arm (4). The vertical movement of the indenter (5) and the connected moving parts (4 and 3) is converted into a circular movement as follows: the vertical movement of (3) is transmitted by the small disc (6), a trapezoidal circular segment. This disc (6) has teeth on its right radius that move the gear wheel (7). This gear wheel (7) is firmly connected to the pointer, which indicates the corresponding degrees of hardness. The trapezoidal disc (6) is set in motion by a pin (8), fixed to the underside of the disc (9), and able to move horizontally in the groove (10) of the block (3).

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[56] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 37

[57] Quotation for the “quadrant type” Durometer: The Shore Instrument & Mfg. Co. Inc.: Bulletin R4: The durometer and elastometer 20th year: an international standard of measurement for hardness and elasticity of rubber, Jamaica, N.Y., Jan.1934, S.1 und quotation for the “round style” Durometer: The Shore Instrument & Mfg. Co. Inc.: Bulletin R6: A2-Durometer (adopted 1944), Jamaica, N.Y., ca. 1945, S.1

[58] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 37

[59] Ebd., S. 37f.

The position of the pin (8) relative to the pivot (11) of the trapezoidal plate (6) can be changed by turning the disc (9) around the upper adjusting screw. The lower adjusting screw can be moved in the slot (12). The closer the pin (8) moves to the pivot (11), the greater the pointer movement on the display scale for any movement of the indicator. Position (13) is a stop screw for setting the minimum spring tension.

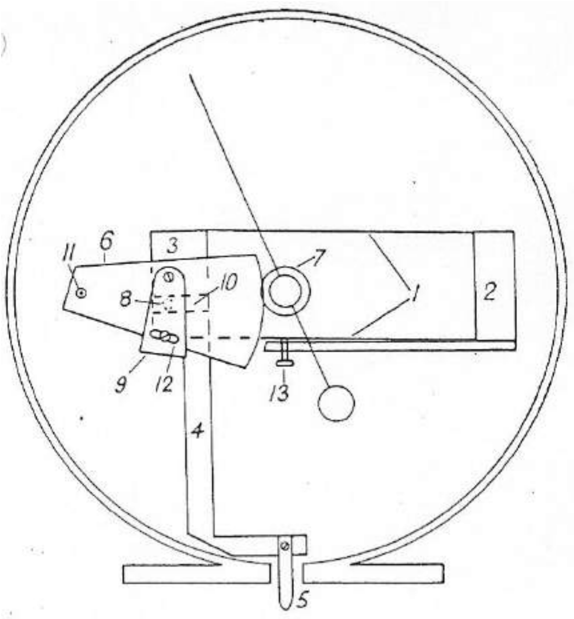

Fig. 21: Schematic sketch of the inner workings of the round Shore A hardness tester ("round style") [60]

SODEN brings differences in the adjustment possibilities of the round durometer in comparison to the classic "quadrant style" durometer, of which one will be examined in more detail below:

- The movement of the pointer on the display scale can be regulated in relation to the penetration travel. For this reason, the display values may not represent a defined penetration travel as with the classic "quadrant type" test device.

7. Advantages and Disadvantages, Criticisms

Some of the advantages and disadvantages described below no longer apply to today's ShA test, or no longer apply in full. In particular, the precision of the procedure has improved considerably in recent decades. Nevertheless, these points of criticism help us to question the test method again and again in a vigilant and critical way.

7.1 General Advantages of the ShA Hardness Testing Method

The great popularity of A.F. Shore devices, which were not only limited to the USA, undoubtedly resulted from the variety of their advantages:

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[60] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S. 37

- Light weight
- Simple manufacturing
- Simple calibration and easy to repair [61]
- Low purchase price
- Few moved and in their form very simple parts (much simpler than a mechanical wristwatch of that time)
- Easy to use
- Testing on the finished part possible
- Non-destructive test method
- Easy to transport
- Due to the geometry of the truncated cone, a round and flat surface lies on the specimen at the beginning of the test. Compared to pointed indenters, this results in a lower sensitivity to different surface structures.
- Over many years pocket testers had hardly any serious competition.[62] The only "competition" were unwieldy and more difficult to operate large laboratory table devices with load weights. Alternative pocket instruments with spring force only emerged when the Shore Durometer was already established, or often these alternatives were a more or less accurate copy of the original from A. F. Shore.
- The low sensitivity of the device produces a uniformity in the results, which was often wrongly attributed to the accuracy of the device.[63]
- The classification of the scale from 0 (very soft) to 100 (infinitely hard) is more logical and comprehensible even for the layman than the usual penetration depth of the floor-standing devices with load weight. This depth of penetration would then be a measure of softness[64] (see chapter 4 "Hardness vs. Softness").
- The handy tester was particularly popular among practitioners and users of elastomers. This is why, when ordering seals or other elastomer components, the hardness was defined using the ShA test method.[65]

7.2 Criticism of the Devices and Their Quality

LARRICK[66] describes the problem in 1940 that if the pocket tester presses too hard, a soft elastomer can be pressed into the bore from which the indenter protrudes. This causes the indenter to be pushed upwards and incorrectly indicates a harder material. With the introduction of the round durometer in 1944 with an increased pressure foot, this danger was reduced because the user would now have to apply a much greater force to obtain the same negative effect as with the small pressure foot of the "quadrant-style" durometer. In addition,

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[61] The technical literature of the 1950s contains precise instructions and recommendations for the independent disassembly and assembly of a classic. "quadrant type" ShA durometers, e.g. in: SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, p.34f.

[62] SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S.34

[63] Ebd., S.34

[64] Ebd., S.9

[65] Ebd., S.9

[66] LARRICK, Lewis: The Standardization of Durometers in: Rubber Age, Sept. 1940, S.389

most laboratories today use durometer stands to press the test equipment to the specimen at the weights specified in the standards (usually 1kg).
In the previous chapter, the various adjustment options for the "quadrant-style" durometer were presented. LARRICK now investigated the partially falsifying influences of the respective adjustments on the measurement results in elaborate test plans. It can be assumed that these discoveries also influenced the later standardization of the method (ASTM D676: 1942) and the further development of Shore Instruments & Mfg. Co..

In a further experiment, the length of the indenter, which was protruding from the device, was varied. When the durometer was placed on a glass plate, it indicated 95.5 or 100 or 105 ShA. Different hardness classes of elastomers were measured with these modified devices. The largest deviations between the device variants were found with very hard elastomers.[67] This effect is relatively insignificant due to the high precision in modern manufacturing and the definition of narrow tolerances in the standard.
The early Shore devices were also criticized for their spring characteristics. The five different Shore A durometers examined by LARRICK[68] all required a lower preload (i.e. < 2oz./57 gr.) to display the value zero than was specified for the devices. Also, to display the value, 100 different weights were required than the required 29 oz. (822gr.). In addition, there were also larger dimensional deviations at the different diameters of the truncated cone. These have a considerable influence on the results. Due to the narrow tolerances in today's standards, this influence is small, but not completely negligible, as Table 3 in the following chapter will show.
In 1942, KLUCKOW criticized the lack of a "possibility of calibration in order to return the obtained shore hardness to a certain unit value by a correction"[69] This objection was solved by the specifications of the spring characteristics (either in table form or as calculation formula) in the currently valid standards for the ShA test method.
In the 1940s, the devices were delivered with so-called control springs made of steel. Such control springs are still available today, but generally reference elastomers are used instead. These historical control springs were usually set to 50 ShA (60 ShA on the Zwick ZET pocket tester). However, even here too great fluctuations were criticized in the literature of the time.[70]
Early pocket test instruments with drag pointer also had a lower display than fixed pointer instruments. This was reasoned by the additional friction caused by the drag pointer. [71]
In addition, the measurement results obtained with ShA hand held durometers ("quadrant type") were criticized. "Since the center of gravity of the housing is not in the axis of the penetrator and the quadrant device widely used in Germany is very sensitive to shear forces, freehand measurements usually have to be associated with a considerable error. “[72] The introduction of durometer tripods has largely solved this problem.

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[67] Ebd., S.390
[68] Ebd., S.390
[69] Translated from KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.83
[70] Vgl. KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.83
[71] Vgl. Ebd., S.84
[72] Translated from HÄNDLER, F. und KAINRADL, P.: IR-Härte, Mikro-Härte und Shore-Härte, Vortragstagung der Deutschen Kautschuk-Gesellschaft, 4.-8.Oktober 1960 in West-Berlin, S.16

7.3 Criticism of the Procedure

It is also important to take a closer look at the device spring. According to SPÄTH it has two functions: firstly, the spring applies the load to the test specimen, and secondly, the spring deformation is used to determine the penetration depth. The load applied by the spring is not constant, but "depends to a large extent on the value to be measured itself". If the aim were to maintain a constant load, this instrument spring would have to be so large that the entire measuring stroke of the test probe would not have a significant influence on the spring force.“[73] If this requirement were met, it would logically no longer be possible to produce pocket-size hardness testers.

In the hardness test methods with load weight, the test pressure is kept constant, whereas in devices with a spring mechanism, the test pressure depends on the hardness of the specimen. SPÄTH criticized in 1956 that "the linear assignment of the hardness scale values in comparison to the deformation of the instrument spring does not do justice to the concept of hardness"[74]. For this reason, the greatest care should always be taken when changes in Shore A hardness are interpreted in comparison with changes in other important properties (e.g. from the tensile test, compression set, etc.).

The random definition of the hardness scale is a very valid point of criticism, as it does not allow simple conclusions to be drawn about other mechanical material properties. According to the definition, 100 ShA corresponds to the hardness of a glass plate. However, the durometer measures rubber materials, which are usually many times softer. This results in an extreme compression of different hardness classes at higher hardness levels (> 90 ShA). The same applies to the lower end of the scale. The value 0 is displayed until the application of a force of 550mN, a minimum value compared to the maximum test force of 8050 mN at 100 ShA. Since the resolution is also extremely low in the lower range, it is recommended to first include ShA hardness values >20 ShA degrees of hardness in evaluations or to use a different test method for softer qualities. This randomness in determining the Shore A hardness scale also explains that there is no linear relationship between the ShA hardness and the moduli of elasticity obtained from static load tests.

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[73] Translated from SPÄTH, Wilhelm: Beiträge zur Technologie der Hochpolymeren – Gummi und Kunststoffe, A.W. Gentner Verlag, Stuttgart, 1956, S.128

[74] Ebd., S.128

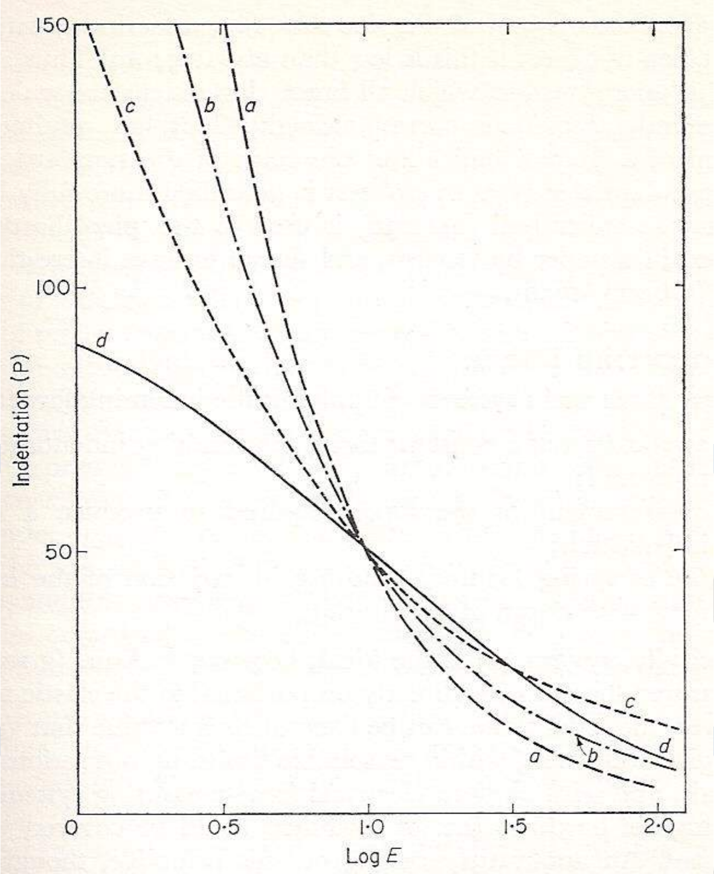
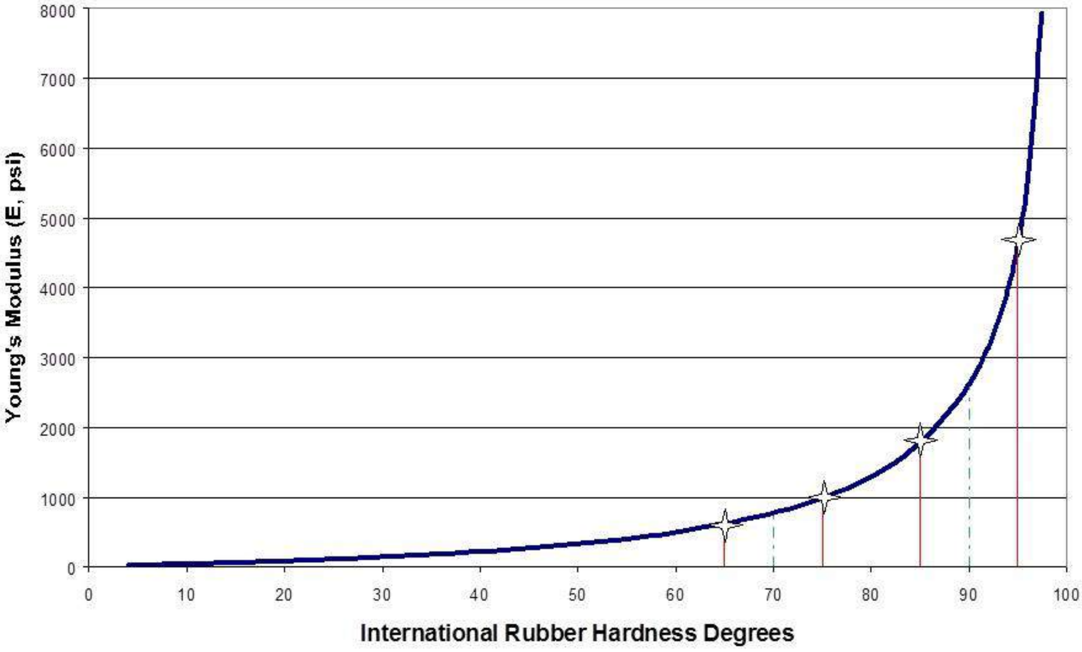


Fig. 22: Ratio between the penetration depth P and the logarithm of the modulus of elasticity E for different indenter geometries:
a = flat cylindrical stamp
b = sphere
c = cone
d = variable force on the indenter (durometer according to Shore)
P and E are in arbitrary units.[75]

This low resolution in the edge areas can be found in a similar way in other hardness testers such as the IRHD method:



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[75] SCOTT, J.R.: Physical Testing of Rubbers, Maclaren & Sons Ltd., London und Palmerton Publishing Co.Inc., New York, 1965, S.93

Fig. 23: Display of the modulus of elasticity over two elastomer materials with a hardness of 70±5 and 90±5 IRHD respectively. Whereas with a compound of 70 IRHD the ±5 tolerance window only corresponds to a range of approx. 300psi, with 90IRHD it is almost 3000 psi. Due to the non-logarithmic representation of the facts, the connection is also quickly apparent to the layman. (1,000 psi ≈ 6.9 N/mm^2) [76]

Already very early the large inaccuracy of the ShA measuring method is criticized. In the mid-1930s, the ShA hardness of one and the same compound measured in different laboratories varied between 10 and 15 degrees of hardness.[77] KIMMICH reported in 1940 at a meeting of the ASTM Committee D11 that "the same piece of rubber, with 5 different Shore hardness testers measured by different people... may differ by more than 5 points"[78]. He also warns that Shore hardness is often mistaken for stiffness, the force needed to compress an elastomer specimen. However, he was able to prove by compression tests that a difference of only 5 degrees of hardness can mean a change of 15-20% in the actual stiffness.[79] However, KIMMICH is already convinced that calibration and improved application of the procedure could reduce the problems mentioned. Important steps towards higher precision were the introduction of round durometers (incl. tripods) with a display scale in one step and a much higher resolution than the "quadrant-style" durometers, the ever more precise standardization of the test procedure (especially in DIN 53 505 and its successor DIN ISO 7619-1) over the last decades, the introduction of digital displays and finally the increased precision of today's precision mechanical manufacturing.

BUIST and KENNEDY have presented a fundamental criticism of the classic indenter principle, whether with spring force or constant load weight, in a patent specification in which they present the hardness tester with constant indenter travel described above. They criticize the fact that the usual hardness measurements on elastomers "are not properly comparative or comparative in the required precision, because the indenter penetrates the elastomer in such a way that the contact pressures between indenter and elastomer can vary in an unknown way".[80]

7.4 Points of Criticism and Suggestions for Improvement of Indenter Geometry

There were repeated suggestions to change the indenter geometry of the ShA pocket tester, be it for practical or scientific reasons. However, nothing could establish itself permanently. But to deal more deeply with the associated arguments can lead to a better understanding of the ShA hardness test.

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[76] HERTZ, D.L. und FARINELLA, A.C.: Shore A Durometer and Engineering Properties, vorgetragen bei: The Fall Technical Meeting of the New York Rubber Group, 24.09.1998, digital verfügbar unter: http://www.sealseastern.com/PDF/Shore-A%20Durometer%20and%20Engineering%20Properties.pdf (Webseite abgerufen am 01.09.2015)

[77] JUVE, A.E.: Recent Developments in Hardness Testing in: American Chemical Society (Hrsg.): Rubber chemistry and technology, Lancaster, Pa, Heft 2, 1957, S.367

[78] Translated from KIMMICH, E.G.: Gummi unter Druck in: Kautschuk, 18. Jg., 1942, S.26

[79] Vgl. hierzu auch: SMITH, L.P:: The Language of Rubber, Butterworth-Heinemann Ltd., Oxford, 1993, S.13

[80] Translated from BUIST, J. M. und KENNEDY, R. L.: Apparatus for Measuring the Hardness of Rubber and similar Materials, Britisches Patent GB617465 (a) – 1949-02-07, S. 1

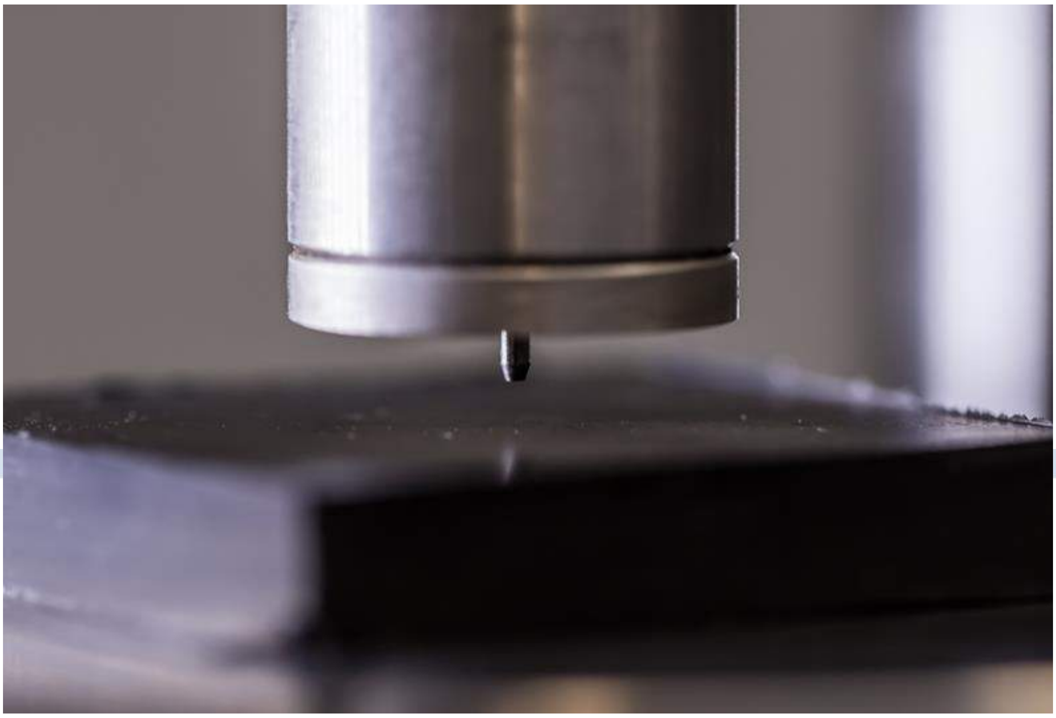

Fig. 24: Side view of the truncated cone-shaped indenter of a modern Shore A testing instrument over an elastomer plate (Photo: O-Ring Prüflabor Richter GmbH)

Early studies repeatedly point out the danger of wear of the truncated cone. Due to its geometry, this danger is higher than with hardness testers with spheres as indenters. It is, therefore, necessary to inspect the truncated cone at regular intervals under a microscope and to replace it if it shows signs of wear or if it fails to meet the specified dimensional tolerances.

Three literature references that proposed recommendations for the modification of the ShA indenter and the associated test procedure might be mentioned as examples:

In 1940, LARRICK[81] criticized the truncated cone as an indenter and proposed a sphere as an indenter instead. This shows much less wear since the pressure load at the edge of the contact between sphere and specimen drops to zero. This is not the case with a cone or truncated cone. Mathematically, he was able to prove that deviations from the diameter tolerances of a sphere have a smaller falsifying influence on the test results than tolerance deviations at the truncated cone. He also suggests that the penetration travel into the elastomer should be 10-15% of the diameter of the sphere indenter and criticizes that some hardness testers have more than 300% of the sphere indenter as the penetration depth.

KLUCKOW[82] proposes 1942 spring pocket testers with a sphere of 5mm diameter. In addition, these devices should exert practically the same load over the entire indenter way in order to achieve comparable results with floor devices (with load weights). He also called for the

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[81] LARRICK, Lewis: The Standardization of Durometers in: Rubber Age, Sept. 1940, S.391f.

[82] Vgl. KLUCKOW, P.: Härteprüfung von Weichgummi in: Kautschuk, 18.Jg., 1942, S.86

introduction of calibration tables with agreed load curves, which would have allowed any user of hardness testers to determine his deviations from an "original device".
SPONAGEL, UNGER and SPIES proposed a modified ShA test in 2003, which uses a cylinder as an indenter instead of a truncated cone. The "easy determination of the sliding or shear modulus by means of the surface properties independent half-space solution makes it possible to combine the technical measure of hardness with the physical measure of shear modulus, which at the same time defines the modulus of elasticity as the physical measure of the stiffness of the material".[83]

8. Important Historical and Current National and International Standards for Shore A Hardness Testing in Comparison

The oldest ShA pocket testers were already in use for more than 25 years before the first ASTM standard for this test method was released. In 1942, the "ASTM Tentative Method of Test for Indentation of Rubber by means of a Durometer" was published. The numerous revisions of the standard show that much was still in the making at that time with this test method: 1944, 1946, 1947 and 1949. Until 1949, all revisions or editions of the standard were still provisional.[84]

Shortly after the first ASTM standard, German standardization published its sheet with specifications for determining the Shore A hardness of finished parts. In March 1943, DIN 53503-2: "Testing of Rubber - Provisional Guideline for Hardness Testing of Finished Parts" was published. DIN 53503 was published on August 1948 in a new edition (Testing of Rubber - Determination of Softness of Soft Rubber - Provisional Guideline for Hardness Testing of Finished Parts), which, however, only represented an unchanged summary of previous standards on hardness testing methods.[85] In these issues of 1943 and 1948 there are no requirements regarding dimensions and tolerances of the ShA pocket tester. In addition, no information is given as to which display value corresponds to which spring force.
It was not until September 1953 that the new edition of DIN 53 505, which replaces DIN 53 503 (08-1948), Section 2, came to be the final standard. It now also had a clear title: "Testing of Rubber Determination of Shore Hardness A" and largely complied with ASTM D 676-49 T and BS 90:1950 Part 20. From this point on, the ShA measuring method, which had already been established in the German industry for a while, was finally established from a standardization point of view.
With DIN 53505 of August 2000, the purely German standardization for the ShA process ends. This last DIN was finally replaced by DIN ISO 7619-1/-2 in February 2012.

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[83] Translated from SPONAGEL, S. ; UNGER, J.; SPIES, K.H.: Härtebegriff im Zusammenhang mit Vernetzung, Bruchdehnung und Dauerfestigkeit eines Elastomers in: KGK Kautschuk Gummi Kunststoffe, 56.Jg., Nr.11, 2003, S.613
[84] Vgl. SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S.9
[85] E-mail notification of the customer service of Beuth-Verlag dated 28.08.2015

The Japanese standard JIS K 6253-3: 2012: "Rubber, vulcanized or thermoplastic - Determination of hardness - Part 3: Durometer method" is based - apart from some technical deviations - on ISO 7619-1 (2010 edition).

In today's landscape of norms, laypersons are surprised that two different ISO standards deal with the testing of ShA hardness. One is ISO 868 (March 2003) and the other is ISO 7619-1 (October 2010). ISO 868 deals primarily with hardness testing of plastics, while ISO 7619-1 explicitly refers to elastomers. The standards have therefore been developed in various working groups.
ISO 868 is closely related to ASTM D2240 and also permits larger tolerances. In ISO 7619-1, the European and German demands for narrower tolerances, as were usual in DIN 53 505, were able to be established. The detailed differences are shown in Table 2 below.

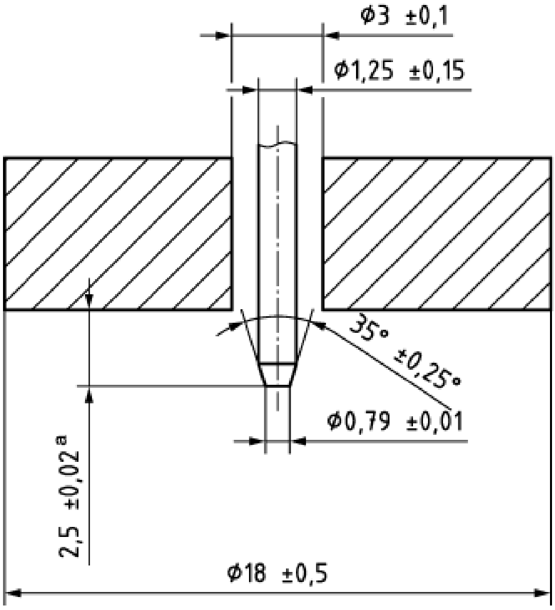

Fig. 25: Sectional drawing of a Shore A Indenter in DIN ISO 7619-1 (Feb. 2012)[86]

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[86] DIN ISO 7619-1 (Edition February 2012): Elastomers or thermoplastic elastomers - Determination of indentation hardness - Part 1: Durometer method (Shore hardness) (ISO 7619-1:2010), P.8, Figure 1 (Fig. shown with permission of DIN Deutsches Institut für Normung e.V. The DIN standard is to be applied in its latest version, available from Beuth Verlag GmbH, Am DIN Platz, Burggrafenstraße 6, 10787 Berlin, Germany. www.beuth.de, www.din.de)

Fig. 26: Indenter and pressure surface of a Shore A test unit (magnification fivefold) (Photo: G. Reiner, O-Ring Prüflabor Richter GmbH)

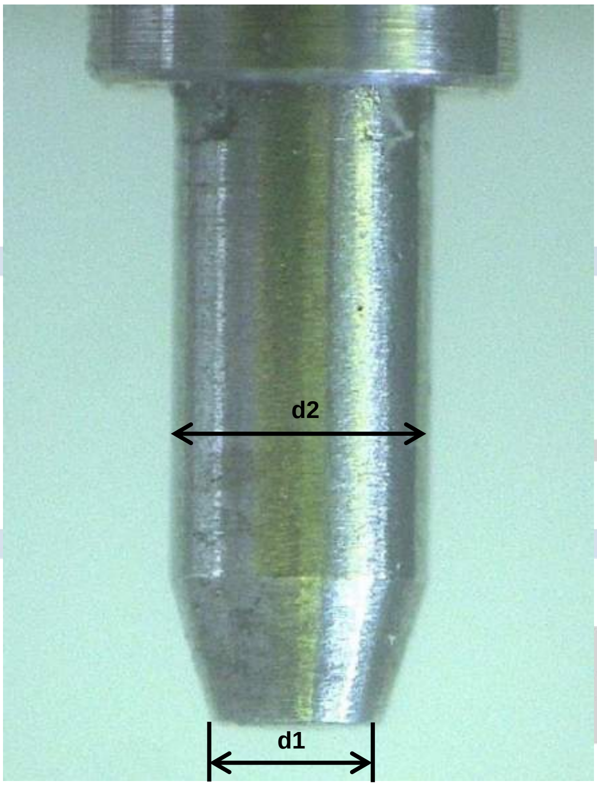

Fig. 27: Shore A - indenter at fifty times magnification:
d1 = Ø 0.79 ±0.01mm
d2 = Ø 1,25 ±0,15mm
(Photo: G. Reiner, O-Ring Prüflabor Richter GmbH)

Parameter Defined in the Standard	**DIN 53 505 (Issue 09-1953)**[87] ***Secluded, Only Informative***	**ISO 7619-1 (Issue 10-2010)**[88]	**DIN EN ISO 868 (Issue 10-2003)**[89]	**ASTM D 2240 (Issue 2010)**[90]	**JIS K 6253-3 (Issue 2012)**
Penetrator	Truncated cone: Ø 0.79 mm ± 0.01 mm 35° ± 1/4° Ø 1.3 mm ± 0.1mm	Truncated cone: Ø 0.79 mm ± 0.01 mm 35° ± 0.25° Ø 1.25 mm ± 0.15 mm	Truncated cone: Ø 0.79 mm ± 0.03 mm 35° ± 0.25° Ø 1.25 mm ± 0.15 mm	Truncated cone: Ø 0.79 mm ± 0.03 mm 35° ± 1/4° Ø 1.27 mm ± 0.12 mm	Truncated cone: Ø 0,79 mm ± 0.01 mm 35° ± 0.25° Ø 1.25 mm ± 0.15 mm
Spring Preload at 0 ShA	56 gr.	550 mN	550 mN	0.55 N	550 mN
Spring Force at 100 ShA	822 gr.	8050 mN	8050 mN	8.05 N	8050 mN
Spring Force Tolerance	± 4gr.	± 37.5 mN	± 75 mN	± 0.075 N	± 37.5 mN
Measuring Path (Full Deflection)	2.540 mm	2.5 mm ± 0.02 mm	2.5 mm ± 0.04 mm	2.5 mm ± 0.04 mm	2.5 mm ± 0.02 mm
Measuring Duration	3 sec.	3 sec. for elastomers, 15 sec. For TPE	(15 ± 1) sec. or if immediate reading is required within 1 sec.	(1 ± 0.1) sec. or by individual agreement	3 sec. for elastomers, 15 sec. for TPE
Measuring Range	0 - 100 (with reference to the development of special devices for the ShA ranges 0-30 and 70-100)	No exact specifications except: ShA is for elastomers in the normal hardness range.	Up to 90 ShA (recommendation)	20-90 (recommendation)	not specified
Specimen Thickness	6mm (for thinner specimens a base of the same material or of the same hardness is required)	Min. 6 mm (max. 3-fold layering allowed)	Min. 4 mm (layers allowed without limitation of number)	Min. 6 mm (layers allowed without limitation of number)	Min. 6 mm (max. 3-fold layering allowed)
Distances	At least 5mm between individual measuring points and from the edge	At least 12 mm from the edge, min. 6 mm from other measuring points	At least 12 mm from the edge, min. 6 mm from other measuring points	At least 12 mm from the edge, min. 6 mm from other measuring points	At least 12 mm from the edge, min. 6 mm from other measuring points

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[87] German standards: DIN 53 505, September 1953: Testing of rubber Determination of Shore hardness A, DK 678.1: 620.178.15

[88] International Standard ISO7619-1 Second edition 2010-10-01 Rubber, vulcanized or thermoplastic – Determination of indentation hardness – Part 1: Durometer method (Shore hardness)

[89] DIN Deutsches Institut für Normung e.V.: DIN EN ISO 868 (Oktober 2003): Kunststoffe und Hartgummi Bestimmung der Eindruckhärte mit einem Durometer (Shore-Härte) (ISO 868:2003)

[90] ASTM –International: Designation: D2240-05 (Reapproved 2010): Standard Test Method for Rubber Property–Durometer Hardness

Parameter Defined in the Standard	**DIN 53 505 (Issue 09-1953)[91]** ***Secluded, Only Informative***	**ISO 7619-1 (Issue 10-2010)[92]**	**DIN EN ISO 868 (Issue 10-2003)[93]**	**ASTM D 2240 (Issue 2010)[94]**	**JIS K 6253-3 (Issue 2012)**
Number of Measured Values	Min. 3	5	5	5	5
Measured Value Evaluation	Single values and mean value rounded to 1 Shore unit/deviation of single values from mean value in %.	Median value	Mean value	Mean value, alternatively median value	Median value
Test Temperature	20° C ± 2°	According to ISO 23529 (mostly: 23° C ± 2°)	Standard climate according to ISO 291 (usually: 23° C ± 2°)	According to ASTM D 1349	According to JIS K 6250: 11.2.1
Clamping Device for Hardness Tester (Durometer Tripod) with Pressure Weight	Optionally possible, pressing of the tester with the force of 1kg	Durometer stand is recommended to press the device with 1 +0.1kg and max. 3.2mm/s	Durometer tripods are recommended to press on the device with 1kg	Two different durometer stands are specified for ShA. Type 2 allows pressing with a max. speed of 3.2mm/s and a pressing force greater than the preload of the spring.	Durometer stand is recommended to press the device with 1 +0.1kg and max. 3.2mm/s
Special Features			Test results can be displayed in abbreviated form. A/15:45 means 45 ShA hardness degrees after 15 seconds of measurement.	All inch values in brackets in this standard are for information purposes only. (see Table1, column for ASTM D2240) Signal device for measuring duration is specified as an option. (Note: This is state of the art for modern ShA hardness testers).	

Tab. 2: Comparative examination of important historical and currently valid national and international standard requirements for the Shore A test method. Significant differences between the standards are marked in red.

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[91] German Norms: DIN 53 505, September 1953: Prüfung von Gummi Bestimmung der Shore-Härte A, DK 678.1: 620.178.15

[92] International Standard ISO7619-1 Second edition 2010-10-01 Rubber, vulcanized or thermoplastic – Determination of indentation hardness – Part 1: Durometer method (Shore hardness)

[93] DIN Deutsches Institut für Normung e.V.: DIN EN ISO 868 (Oktober 2003): Kunststoffe und Hartgummi Bestimmung der Eindruckhärte mit einem Durometer (Shore-Härte) (ISO 868:2003)

[94] ASTM –International: Designation: D2240-05 (Reapproved 2010): Standard Test Method for Rubber Property–Durometer Hardness

As mentioned above, ISO 7619-1 (October 2010) has more precise requirements for the manufacture of equipment than ISO 868 (March 2003). This, of course, has an impact on the quality of the test results. HERRMANN[95] reports on investigations which determined the different measurement uncertainties if the tolerances of the respective standards were met:

Norm-Specific Requirements According to	Achievable **Measurement Uncertainty** for the Measurement Method **ShA**
DIN ISO 7619-1	1.1
ISO 868	4.2

Table 3: Measurement uncertainties that can be achieved if the tolerances of the test instruments are met, according to the two different ISO standards for ShA testing (uncertainty of the hardness test instruments (k = 2))

9. The Problem of Comparability with Other Test Methods

Although Albert F. Shore wrote in 1932 in a contribution to the book "Symposium on Rubber" that the path of the indenter needle was 0.1 inch, all pocket testers of Shore Instruments & Mfg.Co. had maximum indenter paths between 0.092 and 0.095 inch until the mid-1950s. From type number 16901 (March 1955), all subsequent Shore durometers have the standard 0.1-inch travel throughout.[96]

In the early 1950s, the ISO TC45 Committee worked on an international hardness testing method and hardness scale. Significant was the integration of a hardness test method with dead weight, which similar to Shore A had a scale from 0 (very soft) to 100 (very hard). The "Wallace dead weight tester" fulfilled the requirements of this ISO. In practice, however, there were still major differences between test results obtained with the latter device and those obtained with a classic ShA durometer. The British standardization body, which did decisive preparatory work for the ISO Commission, assumed that a ShA hardness tester had an indenter travel of 0.1 inch, but the reality was different, as described above. Since the ShA scale was very well established in the US for specifying materials, large deviations from the new standard (dead weight testing) could not be tolerated. Therefore, two changes were made: First, Shore Instruments & Mfg.Co. changed its maximum indenter travel to 0.1 +0.000/-0.003 inch and the ISO group moved its scale slightly towards the Shore scale. This resulted in good consistencies for certain elastomer types.[97]

However, already in the article quoted above (1957), it becomes clear that even then the comparability of hardness test results obtained with different methods was sometimes very difficult. In addition to natural rubber, some synthetic rubbers were already in use in the 1950s. However, the difference became particularly clear due to the different measurement durations

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[95] HERRMANN, Konrad: Härteprüfung an Metallen und Kunststoffen – Grundlagen und Überblick zu modernen Verfahren, Expert-Verlag, Renningen, ²2014, S.155

[96] JUVE, A.E.: Recent Developments in Hardness Testing in: American Chemical Society (Hrsg.): Rubber chemistry and technology, Lancaster, Pa, Heft 2, 1957, S.370

[97] Nach ebd., S.370f.

of the methods. Ever since, test methods with dead weight have had a reading after a longer load time of the indenter (30 to 60 seconds).

There were also attempts in Germany to convert the DVM softness values (test method with dead weight) into Shore values. But also, here the problem of the different load times arose (ShA hardness: 3Sek. (DIN53505 of Sept. 1953) or DVM softness: 10 seconds (according to DIN-DVM 3503 sheet 1, June 1938)).

In the technical literature, there were also tables for the conversion of result values of the two test methods. Even DIN standard 53503, sheet 2, at times had a reference curve between the two hardness test methods ShA and DVM softness (see Fig. 28). BREUERS and LUTTROPP, however, remarked as early as 1954 when presenting a ShA hardness and DVM softness reference curve: "It should be expressly emphasized that this is a reference curve from which individual qualities can deviate considerably".[98]

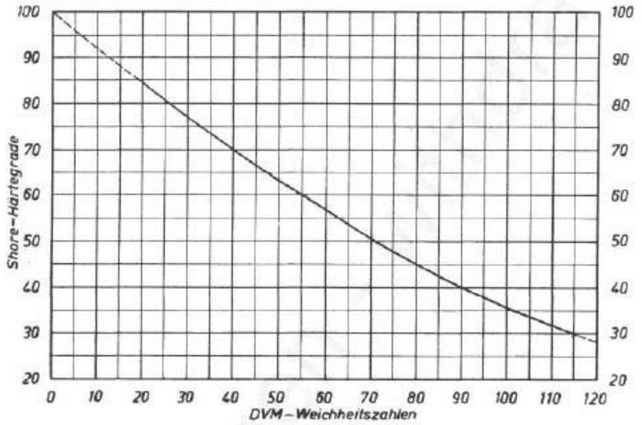

Fig. 28: Historical reference curve for the conversion of ShA hardness grades into DVM softness numbers from the first German standard for the Shore A test method, DIN 53 503, Sheet 2 of March 1943.[99]

An interesting example from the testing practice of the 1950s is a ShA pocket instrument from Zwick GmbH&Co. KG (Fig. 29). It used the reference curve between ShA hardness and DVM softness presented in DIN 53503, Sheet 2 (March 1943) to create a display scale on which both values were displayed.

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[98] Translated from BREUERS, W. u.LUTTROPP, H.: Buna – Herstellung Prüfung Eigenschaften, VEB Verlag Technik, Berlin, 1954, S.228

[99] German standards: DIN 53 503, Sheet 2: Testing of rubber, Preliminary guidelines for hardness testing of prefabricated parts, March 1943, DK 678.1 (Fig. shown with permission of DIN Deutsches Institut für Normung e. V. Decisive for the application of the DIN standard is its version with the latest issue date, available from Beuth Verlag GmbH, Am DIN Platz, Burggrafenstraße 6, 10787 Berlin. www.beuth.de, www.din.de)

Fig. 29: From early on, attempts were made to convert ShA hardness grades into other hardness units. The historical durometer (classic "quadrant type") from Zwick shown on the left is an interesting example of a double scale with ShA hardness (red scale) and DVM softness number (black scale).[100] (Photo: Zwick GmbH & Co. KG, Ulm)

This review makes it clear that the attempt to convert ShA test results into IRHD values and the other way around, which has been repeatedly tried by many parties to this day, is not a modern invention. It becomes clear that from the very beginning of the immense popularity of the Shore A pocket tester, elastomer technologists have been thinking about converting ShA test results into those normally obtained with much more sophisticated table-top hardness testers (with dead weight) using simple tables or reference curves. In the early days of elastomer production this was perhaps still possible for many natural rubber compounds, but today this has become very complex and will probably be reserved for experienced material physicists in the long term.

Now, back to operational practice: When considering the differences between the ShA and IRHD-M test methods and the current conditions in the elastomer industry, it quickly becomes clear why a simple conversion is not possible:

- *Indenter type*: the indenter in the ShA method is a truncated cone, in the micro-hardness test (IRHD-M) it is a sphere.
- *Load time or measuring duration:* Most standards require a reading after 3 seconds for ShA, while the result is read after 30 seconds to determine the IRHD characteristic values. In the case of compounds with a strong flow tendency, there will be significant differences in the various hardness values.
- *Applying force to the indenter:* In the ShA process, the indenter is pressed into the material by spring force, which changes with the hardness of the material. In the IRHD-M process, the indenter is pressed into the material by a constant load weight.
- *Compounds:* Today, hundreds of thousands, if not millions, of different elastomer compounds are used worldwide every day. There are a number of different polymer types, compound components and crosslinking systems that are difficult to keep track of, which makes it practically impossible to predict whether the different hardness values will be comparable.

The usually large tolerance window for hardness specifications on elastomer compounds and products is helpful for the practitioner in this respect. Most finished parts are specified in a

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[100] SODEN writes as early as 1952 of the existence of such Zwick test instruments with double scale: SODEN, A.L.: A Practical Manual of Rubber Hardness Testing, MacLaren & Sons Ltd., London, 1952, S.43

window of ±5 degrees of hardness, but the compounds typically lie within a tolerance range of max. ±3 degrees of hardness. This often allows the target window of ±5 degrees of hardness to be achieved relative to the nominal hardness of the formulation, despite geometry and processing influences on the finished part.

Despite the difficulties described, which make simple conversion impossible, there are still diagrams in the current technical literature which show the approximate relationships between ShA, ShD and IRHD. Such a diagram can be found, for example, in Roger BROWN's "Physical Testing of Rubber", the current standard work on elastomer testing.[101]

Finally, it should be noted that modern material physics has also addressed this problem. The work of BRISCOE and SEBASTIAN (1993)[102] should be mentioned here, who analyzed the penetration process during ShA testing with the help of elasticity theory. They then compared the theoretical relationships between ShA and IRHD hardness and the corresponding moduli of elasticity. Towards the end of their article they also give a rough approximation formula for the mutual conversion of IRHD and ShA values, with information on the limitations of this approximation.
In 2011, MIX and GIACOMIN[103] developed dimensionless durometry. Through their research it should be possible to determine the modulus of elasticity of the material from the hardness measurement. In addition, they say that their "results can also be used to convert different hardness scales, not only between hardness scales of the same indenter geometries, but also between those of different geometries"[104].
The reader with a deeper interest in the theory should be referred to these interesting sources, but their application is probably too complex and costly for the industrial practitioner.

10. Recommendations for Today's Testing Practice

For many users, hardness is the only material test that is carried out. Hardness deviations from the nominal value are then evaluated correspondingly high. Therefore, the question should be asked why hardness testing is important and in which areas it does not help:

10.1 Choice of a Suitable Hardness Testing Method

Due to the great popularity and simplicity of the ShA hardness measurement method, this test method is usually the first choice. However, in many cases this decision should first be critically questioned:

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[101] BROWN, Roger: Physical Testing of Rubber, Springer Verlag, New York, ^{4}2006 S.131
[102] BRISCOE, Brian J. und SAVIO SEBASTIAN, K.: An Analysis of the “Durometer” Indentation in: American Chemical Society (Hrsg.): Rubber chemistry and technology, Lancaster Pa, Jg. 66, Heft 5, Nov. 1993, S.827-836
[103] MIX, A.W. und GIACOMIN, A.J.: Dimensionless Durometry in: Polymer Plastics Technology and Engineering, 50, 2011, S.288-296
[104] MIX, A.W. und GIACOMIN, A.J.: Dimensionless Durometry in: Polymer Plastics Technology and Engineering, 50, 2011, S.295

- At the beginning it must be clarified whether a standard-compliant test is possible. In the case of ShA, this means whether a plane-parallel test specimen with a thickness of at least 6 mm (ISO 7619-1) is available or can be produced by layering. It must also be examined whether the standardized minimum distance of 12 mm from the edge of the specimen can be maintained.
  If the above requirements are not met and the finished parts are nevertheless to be tested, the following points may be considered: "Geometry-related deviations from the standard hardness may occur for finished part tests. On molded parts, it must be agreed at which point the measurement will be carried out. (...) In practice, it is particularly important to ensure that the test specimen has plane-parallel locations. If necessary, profile cuts can be made from finished parts. If the prerequisites for reproducible measurements are fulfilled on certain finished parts, the hardness testing method is a simple and effective method of material testing." [105] As already indicated above, a test that does not conform to the standard must be noted in the test results, ideally with a photo of the test situation.
- If the hardness is completely unknown, it must first be determined by preliminary examinations which hardness outcome can be expected. In the marginal areas of the ShA scale, the resolution is very low. Therefore, for hardness values less than 20 ShA degrees of hardness, test methods for very soft elastomers should be used, e.g. ShA0 according to ISO 7619-1 or ShE or ShOOO according to ASTM D 2240. For ShA test results greater than 90 degrees of hardness, for example, the ShD method according to ASTM D 2240 should be used alternatively.[106]

The following points also need to be considered:

- Type of measuring task; a distinction must be made between routine measurements (...) and material tests [Where possible, the ShA test method with 3 seconds will certainly be preferred to the IRHD method with 30 seconds test time for numerous serial tests]. (…)
- Permissible damage to the specimen
- Permissible uncertainty of measurement
- Test costs
- Available Test Equipment "[107]

10.2 Preparation of Test Specimens and Performance of Hardness Tests

The most important prerequisite for reproducible hardness measurement is plane-parallel samples. When testing finished parts that do not conform to standards, pre-defined compromises must be made here, such as special mounting brackets or fixings, since "even

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[105] Translated from BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Härteprüfung, Internetveröffentlichung, 05/2014, S.4 (http://www.o-ring-prueflabor.de/files/fachwissen_h__rtepr__fung_05_2014_1.pdf)

[106] See also the recommendations: ASTM –International: Designation: D2240-05 (Reapproved 2010): Standard Test Method for Rubber Property–Durometer Hardness, S.12, Table X1.1

[107] HERRMANN, Konrad: Härteprüfung an Metallen und Kunststoffen – Grundlagen und Überblick zu modernen Verfahren, Expert-Verlag, Renningen, ²2014, S.148

slightly hollow samples lead to considerable measurement errors."[108] According to HERRMANN, "a conditioning time of 16h is sufficient for many types of rubber and plastics".[109] For certain plastics, such as polyamide, the significant influence of humidity content on various material properties, such as tensile strength or hardness, is generally known. There are similar effects with elastomers, but less severe than with polyamide. In this context, colored compounds with hydrophilic and mineral fillers, such as various FKM compounds, should be emphasized. Pre-drying for a few hours can result in considerable differences in strength in the tensile test.[110] For the hardness, this influence is smaller and vanishes in the random measurement uncertainty.

Typically, the hardness of O-rings is measured as the micro-hardness (IRHD-M according to ISO 48). The very practice-oriented ASTM D 1414 - 94 (Reapproved 2008) Standard Test Methods for Rubber O-Rings allows O-rings to also be tested using the ShA test method under certain conditions. However, it is noted in "Note 6" that the ShA test method is not recommended for O-rings with a cord thickness of less than 6mm. If tests are carried out on O-rings with lower cord thicknesses, there may be a deviation from the hardness values determined on standard specimens. Since the full deflection of the indenter needle is 2.5 mm, ASTM D 1414 recommends the use of a holder which allows two O-rings to be superimposed when testing O-rings with a cord thickness of less than 3 mm. The result should be a test specimen that is higher than the full deflection of the indenter needle.[111] However, the latter recommendation for stratification of O-rings is not applied in the testing practice of our laboratory, since O-rings are generally measured according to ISO 3601-5 with the test standard of ISO 48M.

10.3 Conclusions of the Test Results

The following explanations have already been published online by the author of this article together with Bernhard Richter (www.o-ring-prueflabor.de), but may be quoted here for the sake of completeness:

- The hardness gives a reference value for the deformation behavior of the material. A hard material (90 Shore A / IRHD-M) has a higher resistance to gap extrusion at high pressures (> 70 bar) and also offers greater protection against assembly damage. A soft material (50 Shore A / IRHD-M or less) deforms more easily and can better seal surface defects, e.g. a mold parting burr in a plastic molded part. Therefore, the choice of the nominal hardness determines the functionality of a gasket within a certain range.
- “Hardness is often mistakenly used as a measure of the stiffness of a material. Although both the hardness and the tensile-stretch diagram (see tensile test) indicate something about the stiffness of an elastomer, these are fundamentally two different types of

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[108] Translated from Ebd., S.149

[109] Translated from Ebd., S.150

[110] BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Zugversuch - Prüftechnische Grundlagen und Empfehlungen für die praktische Anwendung, Internetveröffentlichung, 10/2014, S.23 (http://www.o-ring-prueflabor.de/files/fachwissen-zugversuch_10_2014.pdf)

[111] ASTM – International: Designation: D1414 – 94 (Reapproved 2008): Standard Test Methods for Rubber O-Rings, S.5, Note 6

deformation. Tensile strain measurements involve large deformations of the whole mass, whereas hardness tests involve only small deformations. Even if hardness and stiffness (represented by a tensile strain diagram) would have a better correlation, the generally given fluctuation range of +/-5 hardness points in the Shore A measurement would already correspond to a scatter range of approx. 15-20% in stiffness, and for hard materials (>80 Shore A) even significantly more. This shows that the determination of the hardness alone is insufficient for the design of elastomer components for which a defined stiffness is important."[112] For example, the hardness values on O-rings provide only a rough indication of the resistance to gap extrusion. Further valuable indications of resistance can be deduced from a tensile test using stress values and strength values.

- Hardness can only be regarded as a material parameter if tests are carried out in accordance with standards, meaning on test plates.
- As a finished part test, hardness offers a simple way of formulation identification if this is evaluated together with other tests (e.g. density). (…)
- The hardness test is with regard to the instrument capability significantly worse than other measuring methods, therefore a deviation from the nominal value does not necessarily represent a significant reduction in quality. This can only be reliably assessed in connection with other tests (e.g. by the compression set or the tensile set). Precise information can be found in the appendices of the respective standards.[113] There are also studies on the reproducibility of hardness testing in the technical literature.[114] As a general rule for the user, due to the poor instrument capability, tolerance windows smaller than ± 5 degrees of hardness should not be required in the order or drawing.
- Whether a material is sufficiently vulcanized can only be very inaccurately indicated by hardness measurement. Today, there are more effective test methods for this, such as the compression set. The fact that hardness measurements are still incorrectly used to determine the degree of vulcanization is probably due to historical reasons. The DVM softness tester, for instance, was used to evaluate the different degrees of vulcanization from step heaters of elastomer components. For example, the recovery of the test specimen after removal of the test load was recorded in 5 second steps. This gave a statement about the plastic and elastic proportions in the compound and indirectly about the degree of cross-linking. This, however, was a more complex procedure that required specialist knowledge and a great deal of experience.[115]
- The hardness is often also measured on pre-aged samples, e.g. after hot-air contact. Since hot-air aging occurs first and foremost in the outer layers of an elastomer, hardness measurement is a good way of showing small changes in the surface layers. However, the IRHD-M test method here will be preferable to the ShA test method due to the lower penetration depth and higher precision.

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[112] SMITH, L.P: The Language of Rubber, Oxford, 1993, S.12

[113] BLOBNER, U. und RICHTER, B.: Fachwissen Prüfverfahren für Elastomere: Härteprüfung, Internetveröffentlichung, 05/2014, S.3f. (http://www.o-ring-prueflabor.de/files/fachwissen_h__rtepr__fung_05_2014_1.pdf)

[114] z.B. BROWN, R.P. und SOEKARNEIN, A.: An Investigation of the Reproducibility of Rubber Hardness Tests in: Polymer Testing, Elsevier Science Publishers Ltd., 10.Jg., 1991, S.117-137

[115] Vgl. KLUCKOW, Paul: Die Praxis des Gummichemikers, Berliner Union, Stuttgart, 1954, S.252f.

- When testing finished parts that do not conform to standards, it is important to consider the influence of the height of the specimen on the hardness. The subject was scientifically investigated by BASSI and CASA in 1986.[116] The following diagram (Fig. 30) illustrates the relationships for the practitioner in a simple form:

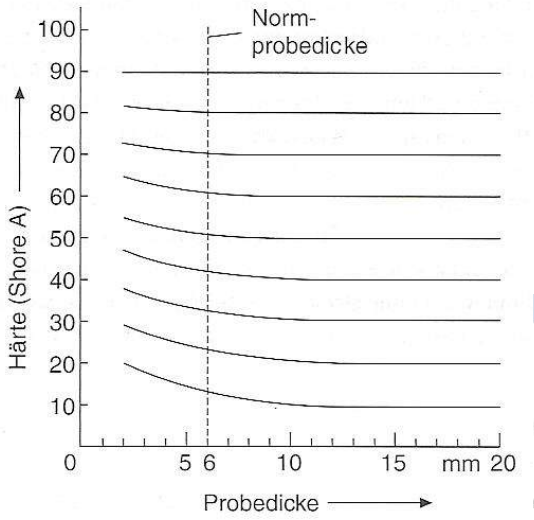

Fig. 30: Influence of specimen thickness on the results of the ShA hardness test, shown on nine qualities with different hardness levels [117]

- When comparing ShA test results, the actually applied test time, i.e. the penetration time of the indenter until the measured value is read, must also be considered. According to ISO 7619-1, this is usually only 3 seconds, while ISO 868 requires five times this time (15 seconds). The following diagram (Fig. 31) illustrates the correlations:

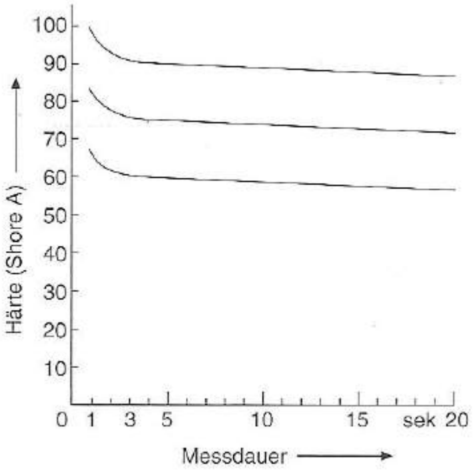

Fig. 31: Influence of the measuring duration on the results of the ShA hardness test, shown on three qualities with different hardness levels [118]

- Practically, all elastomer components are subject to completely different static loads in their practical application than they are subjected to hardness testing. Likewise, hardness testing does not provide any information on the dynamic load capacity of a

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[116] BASSI, A.C.; CASA, F.; MENDICHI, R.: Shore A Hardness and Thickness in Polymer Testing 7, Elsevier Applied Science Publishers Ltd., 1987, S.165-175

[117] NAGDI, K.: Gummi-Werkstoff Ein Ratgeber für Anwender, Dr. Gupta Verlag, Ratingen, ²2002, S.286

[118] Ebd., S.286

material. "It is hardly possible to verify desired properties like "frequency" or "spring rate" for the later finished part with this test."[119]

- Differences in the hardness results can also in rare cases originate in the quality of the test plates. For example, the compound produced in the laboratory may be poorly mixed. If the vulcanization agents or fillers are distributed unevenly, different hardness values may occur on one and the same plate. In the case of incomplete test plates (incomplete mold filling), hardness deviations can also be expected within this test plate.[120]
- A special field of hardness testing is the investigation of material behavior at low temperatures. In the glass transition temperature range, elastomers harden relatively quick and change to a glass-like state, resulting in a significant increase in hardness. ECKER already carried out research on low-temperature ShA measurements in the 1950s. He describes the penetration process of the indenter as a superposition of static tensile and compression deformations. "It is, therefore, not surprising that the temperature dependence of the Shore hardness is symbiotic with that of the static or dynamic modulus of elasticity. However, it should not be overlooked that in this determination the surface tension influences the measurement particularly strongly. The differentiation of the individual qualities is not as distinct as with the E-modulus determinations [in the cold] (...)".[121] This special field of hardness testing is currently standardized in ISO 3387: Rubber Determination of crystallization effects by hardness measurements (Edition 07-2012). However, today dynamic mechanical analyses (DMA) provide much more information about the physical behavior of elastomers in low temperatures, which is why hardness measurement in low temperatures has become much less important.

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[119] Bußmann, M.: Elastomermischungen spezifizieren und prüfen in: KGK Kautschuk Gummi Kunststoffe 52. Jahrgang, Nr. 11, 1999, S. 744

[120] Vgl. KLUCKOW, Paul: Die Praxis des Gummichemikers, Berliner Union, Stuttgart, 1954, S.293

[121] Translated from ECKER, R.: Statische und dynamische Verformungseigenschaften von Kautschuk-Vulkanisaten und anderen Hochpolymeren, Vortragstagung Deutsche Kautschuk-Gesellschaft, München, 1954, in: SPÄTH, W.: Bemerkungen zur Shore-Härte in: Gummi und Asbest, 8.Jg., 1955, S.420