

Guide to

Properties and types of rubber

UDC [678.4 + 678.7]:678.01

Confirmed
January 2011

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents

AVA

Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Rubber Standards Committee (RUM/-) to Technical Committee RUM/15 upon which the following bodies were represented:

- British Rubber Manufacturers' Association
- Malaysian Rubber Producers' Research Association
- Ministry of Defence
- RAPRA Technology Ltd.
- Society of Motor Manufacturers and Traders Limited

This British Standard, having been prepared under the direction of the Rubber Standards Committee, was published under the authority of the Board of BSI and comes into effect on 31 July 1986

© BSI 04-1999

The following BSI references relate to the work on this standard:
Committee reference RUM/15
Draft for comment 84/35977 DC

ISBN 0 580 15208 1

Amendments issued since publication

Amd. No.	Date of issue	Comments

Contents

	Page
Committees responsible	Inside front cover
Foreword	ii
1 Scope	1
2 Rubbers commercially available	1
3 Properties of vulcanized rubbers	1
4 Types of rubber	13
5 Cellular materials	19
6 Ebonite	20
7 Latex	20
8 Designing a rubber component	20
Appendix A British Standards for rubber and rubber products	23
Appendix B Index	23
Figure 1 — Scheme for selection of type of rubber	22
Table 1 — Rubbers in general use	2
Table 2 — Less common rubbers	3
Table 3 — Relationship between hardness and medium strain shear modulus	3
Table 4 — Heat resistance of rubbers	8
Table 5 — Low temperature resistance of rubbers	10
Publications referred to	26

Foreword

This British Standard has been prepared under the direction of the Rubber Standards Committee. It originated from a draft Defence Standard prepared by the Rubbers, Plastics and Adhesives subcommittee of the Defence Engineering and Equipment Standardization Committee.

The guide provides users and designers with basic information on the properties of rubber and how these may be best utilized in finished products. Rubber is a generic term for a group of polymeric materials whose main characteristic is a unique ability to undergo large elastic deformations, in tension, compression, shear or torsion, without rupture and to recover almost completely after such deformation. This characteristic is exploited in a wide variety of end-uses ranging from disposable household goods and vehicle tyres (the main use of rubber) to large mountings and bearings required to last the life-span of the building or bridge they support. Other uses include adhesives, electrical insulation and chemical plant linings. In a document of this length such a range of applications cannot be considered in any detail, and for this reason some emphasis has been placed on the properties of rubber as an engineering material, although the information given is of wider interest. In engineering, rubber is mainly used as a seal or as a spring; it is also used in hoses and belting of various descriptions. It should be noted that British Standards are available for several of these and other applications of rubber. A comprehensive list, comprising test methods, specifications, and other related standards, is given in a classified format in BSI Sectional List SL 12 "Leather, plastics, rubber".

NOTE Further details about SL 12 are provided in Appendix A.

The material is usually in the form of vulcanized rubber. Vulcanization is the insertion of chemical crosslinks at intervals along adjacent rubber molecular chains. The type and density of the crosslinking depend upon the time and temperature of the process as well as the amount and type of vulcanization ingredients used in the formulation. The properties of the vulcanized rubber are affected by the type and density of crosslinking. Thermoplastic rubbers rely on crystalline or glassy domains for their strength and thermoplasticity.

Initially the only rubber polymer available was that produced from tree latex, i.e. natural rubber, but since the 1930's there has been tremendous activity in the field of polymerization with the development of a large number of synthetic rubber polymers. This vast increase in the number of rubber polymers available has greatly increased the complexity of choice of a suitable material.

The inherent properties of vulcanizable rubber polymers can be varied over a wide range by differences in compounding. Compounding involves the addition of powder and liquid ingredients to the rubber polymer. The ingredients added fall into two classes, those essential to the production of a vulcanizate having the desired properties, and those used to minimize the cost of the end product. Key ingredients in the rubber compound include the vulcanization system, fillers that impart specific properties, and antidegradants.

All rubber vulcanizates are liable to degradation during storage and service although the rate of deterioration of some rubbers can be considered to be extremely slow. When made to appropriate specifications, and when properly packaged and stored, most rubbers will remain in a serviceable condition for many years. A controlled system of storage is necessary to ensure rubbers are issued for use in a serviceable state (see BS 3574). The life in service is dependent on the service conditions and advice should be sought at an early stage of the design study. Factors affecting the life of vulcanized rubber are discussed in 3.5. Throughout this standard the term "rubber" is intended to cover both natural and synthetic rubbers in dry and latex form. This and other terms are used in accordance with definitions given in BS 3558.

An index to the principal clauses in this standard is included as Appendix B.

WARNING NOTE. The guide refers to the use of substances and/or test procedures that may be injurious to health if adequate precautions are not taken. It refers only to technical suitability and in no way absolves either the supplier or the user from statutory obligations necessary to meet the requirements of the Health and Safety at Work, etc. Act 1974, relating to health and safety at any stage of manufacture or use.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 26, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

1 Scope

This British Standard gives designers and users of rubber products guidance on the properties and types of rubber, associated test methods and terms used in the rubber industry. It draws attention to relevant British Standards in this field. Guidance is also included on designing a rubber component for a particular end-use.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

2 Rubbers commercially available

The chemical names of rubbers in general use are given in Table 1, together with their abbreviations as given in BS 3502-3 and, where appropriate, their common names.

Applications of rubbers involve contact with environments where their resistance to heat, oil and atmospheric conditions have to be considered. The rubbers available provide a range of performance under these conditions. However, a compromise is usually necessary and expert advice should be sought early in the design study. Generally it is advantageous to carry out an initial trial under service conditions before finalizing the formulation. An outline guide to the selection of basic rubber is given in 8.3.

Trade names should not normally be used on drawings or in specifications. Only the generic name should be used except in instances where a particular type/grade has to be specified for technological reasons.

In addition to the rubbers listed in Table 1, BS 3502-3 also contains the names of rubbers that are much less common, and in some instances there is no current production of the type mentioned. The names of these rubbers are listed in Table 2.

Attention is also drawn to the increasing availability of thermoplastic rubbers (see 4.20).

3 Properties of vulcanized rubbers

3.1 General

Rubbers are viscoelastic materials of low rigidity exhibiting large strain elasticity. The deformations imposed on rubber components (typically 20 % to 50 % strain in compression or shear) are far larger than those encountered for most other materials, and the stress-strain relationships are correspondingly more complex. In general, it is not possible to characterize rubbers by a unique combination of moduli, such as shear and bulk moduli, as the shear moduli of rubbers vary with strain. It is often possible, however, to predict the performance of a component from the shear modulus at a known strain.

The ability of a rubber to store elastic energy depends largely on the type of polymer used. In general, polymers having relatively high glass transition temperatures exhibit the highest energy losses during deformation. These energy losses are exploited in components intended to damp motion, but generally the higher the damping obtained the more sensitive are the modulus and damping to frequency and temperature.

The tensile strength of a rubber is low compared with other materials but the energy storage capacity at break can be greater than that of an equivalent mass of steel. Failure of rubber components rarely occurs by simple tensile failure; tearing or fatigue crack growth is more likely.

A major factor determining the strength of rubber is an ability to crystallize under the influence of an applied strain. Rubbers possessing this ability (e.g. NR and CR) are intrinsically strong while those that do not crystallize rely on the incorporation of reinforcing fillers to impart adequate strength.

A limitation on the use of rubbers in some applications is the effect of certain fluids. The extent of swelling or property change in a given fluid is critically dependent on both the rubber and the fluid. Selection of a rubber for a given application should take into account its resistance to any fluids it is likely to be in contact with in service. A similar consideration applies to the effects of temperature and the climate in which a product is to be used.

3.2 Stress-strain properties

3.2.1 Introduction. Rubbers exhibit non-linear stress-strain behaviour, and as a measure of stiffness, Young's modulus only applies to strains of the order of a few percent. Thereafter "modulus" will vary with the magnitude of the strain, and it is also influenced by the mode of deformation and, as will be described later, by the conditions of any cycling. Relationships between low strain and high strain measurements can sometimes be established for individual rubber types, but a general correlation suitable for design purposes should not be assumed.

Common measurements of stiffness used by the rubber industry are hardness and stress at a given elongation.

Table 1 — Rubbers in general use

Abbreviation	Chemical name (based on BS 3502-3)	Common name
ACM	Copolymers of ethylacrylate or other acrylates and a small amount of a monomer which facilitates vulcanization	Polyacrylic (see note 1)
AU	Polyester urethane	Polybutadiene
BR	Butadiene rubbers	Bromobutyl
BIIR	Bromo-isobutene-isoprene	Chlorobutyl
CIIR	Chloro-isobutene-isoprene	Epichlorohydrin
CO	Polychloromethyloxiran	Neoprene
CR	Chloroprene rubbers	Chlorosulphonated polyethylene
CSM	Chlorosulphonylpolyethylene	Epichlorohydrin
ECO	Ethylene oxide and chloromethyloxiran copolymers	EPDM
EPDM	Terpolymers of ethylene, propylene and a diene with the residual unsaturated portion of the diene in the side chain	Ethylene-propylene (see note 1)
EPM	Ethylene-propylene copolymers	Fluorocarbon
EU	Polyether urethane	Polypropylene oxide
FPM	Rubbers having fluoro and fluoroalkyl or fluoroalkoxy substituent groups on the polymer chain	Butyl
GPO	Copolymers of propylene oxide and allyl glycidyl ether	Polyisoprene
IIR	Isobutene-isoprene rubbers	Nitrile
IR	Isoprene rubber, synthetic	Natural rubber
NBR	Acrylonitrile-butadiene rubbers	Polysulphide rubbers
NR	Isoprene rubber, natural	Silicone rubbers
OT (EOT)	Polysulphide rubbers ^a	SBR
Q group	Silicone rubbers ^b	Carboxylated nitrile
SBR	Styrene-butadiene rubbers	Carboxylated SBR
XNBR	Carboxylic-acrylonitrile-butadiene rubbers	
XSBR	Carboxylic-styrene-butadiene rubbers	

NOTE 1 AU and EU are generally polyurethane rubbers.

NOTE 2 Common and widely used trade names are Neoprene (CR), Hypalon (CSM), Viton (FPM), Thiokol [OT (EOT)].

^a This is not defined in BS 3502-3.^b FEMQ Silicone rubbers having both methyl and fluorine substituent groups on the polymer chain.

FVMQ Silicone rubbers having methyl, vinyl and fluorine substituent groups on the polymer chain.

MQ Silicone rubbers having only methyl substituent groups on the polymer chain, such as dimethyl polysiloxane.

PMQ Silicone rubbers having both methyl and phenyl substituent groups on the polymer chain.

PVMQ Silicone rubbers having methyl, vinyl and phenyl substituent groups on the polymer chain.

VMQ Silicone rubbers having both methyl and vinyl substituent groups on the polymer chain.

Table 2 — Less common rubbers

Abbreviation	Chemical name (based on BS 3502-3)	Common name
ABR	Acrylate-butadiene rubbers	Chlorinated polyethylene Polyisobutylene
AFMU	Terpolymer of tetrafluoroethylene-trifluoronitrosomethane and nitrosoperfluorobutyric acid	
ANM	Copolymers of ethylacrylate or other acrylate and acrylonitrile	
CFM	Polychlorotrifluoroethylene	
CM	Chloropolyethylene	
IM	Polyisobutene	
NCR	Acrylonitrile-chloroprene rubbers	
NIR	Acrylonitrile-isoprene rubbers	
PBR	Vinylpyridine-butadiene rubbers	
PSBR	Vinylpyridine-styrene-butadiene rubbers	
SCR	Styrene-chloroprene rubbers	Ethylene-acrylic
SIR	Styrene-isoprene rubbers	
	Carboxylated copolymer of ethylene and methyl acrylate ^a	
	Polynorbornene ^a	
	Phosphonitrile fluoroelastomer ^a	

^a Not standardized nomenclature as listed in BS 3502-3.

3.2.2 Hardness

3.2.2.1 General. Hardness, as measured by an indentation test, is a semi-empirical measure of modulus (see BS 903-A26). The strains involved in a hardness measurement are complex and not well defined, but an approximate relationship between hardness and a medium strain shear modulus (10 % to 25 % shear strain) exists as given in Table 3. The measurement is widely used because of its simplicity and applicability to the surfaces of components. As rubber is a poor conductor of heat the effect vulcanization has on properties may vary throughout the thickness of a component, and this should be taken into account when using hardness tests as a means of quality control of thick products. Rubber components made from the same material may vary in hardness due to their shape and size.

Table 3 — Relationship between hardness and medium strain shear modulus

Hardness	Shear modulus G
IRHD	MN/m ²
30	0.30
40	0.45
50	0.65
60	0.95
70	1.35

NOTE The relationship is intended as a guide for it will vary according to rubber type and composition and method of test. The shear moduli quoted are for a series of NR vulcanizates tested at 25 % shear strain.

3.2.2.2 International Rubber Hardness Degrees.

Hardness is internationally quoted in International Rubber Hardness Degrees (IRHD), the scale being so chosen that zero represents a material of infinite softness (modulus of elasticity of zero) not practically achievable, and 100 a material of infinite hardness (modulus of elasticity of infinity). For most applications, the operative range is from 30 IRHD to 90 IRHD and it is usual in specifications for rubbers to quote a hardness tolerance to allow for slight differences in the materials and manufacturing techniques used. Elastic bands and household gloves are typically made of a soft rubber of hardness 35 IRHD to 45 IRHD, whilst a shoe heel will have a hardness usually in excess of 80 IRHD. Other examples are 50 IRHD to 60 IRHD for engine mountings and pipe sealing rings, and 60 IRHD to 70 IRHD for pneumatic tyre treads.

NOTE In many specifications a hardness range of 10 (or more generally + 5, – 4) IRHD is used, but in critical applications ± 2 IRHD is feasible and necessary to avoid large variations in some properties.

Hardness is thickness dependent and this feature is accounted for in the test methods described in BS 903-A26. Thus method N (normal test) of BS 903-A26 requires a standard thickness of 8 mm to 10 mm; it is not accurate on test pieces less than 4 mm thick. For thinner test pieces a microtest is described in method M of BS 903-A26, and provided that the test piece has a thickness of 2 ± 0.5 mm the result approximates to the one obtained by method N. In other cases the results will be only an apparent hardness dependent upon the dimensions of the test piece. Since there is some commercial use of very soft rubbers, the scope of BS 903-A26 has been extended to include rubbers of hardness less than 30 IRHD.

3.2.2.3 Shore hardness. The Shore hardness scale is widely used particularly in the USA and readings in IRHD are approximately the same as those of the Shore durometer type A over the range 30 IRHD to 90 IRHD. A direct conversion to IRHD is acceptable for many rubbers but with a few rubbers, such as chlorosulphonated polyethylene, large differences can occur.

NOTE Shore hardness should not be quoted on any drawing or specification.

3.2.2.4 Apparent hardness on curved surfaces. The methods mentioned in 3.2.2.2 for the determination of hardness necessitate the use of a flat test piece and are therefore not applicable to components having curved surfaces. It is, however, frequently desirable that the hardness of a component having a curved surface be determined and for this purpose other methods described in BS 903-A26 can be used. Test results obtained on curved surfaces are, however, arbitrary values applicable only to the particular component supported in a particular way and may differ from the true hardness by as much as 10 IRHD. Provided that this is recognized and due allowance made for these effects the methods can be used for controlling production of finished components.

3.2.3 Shear modulus. Shear modulus is of particular relevance to the design of shear mountings and of bridge bearings, which need a high vertical stiffness to prevent changes in the height of the bridge deck but a low horizontal stiffness to prevent excessive loads on the bridge support resulting from expansion or contraction of the deck. The shear stiffness, K , of a rubber block is given by the equation:

$$K = \frac{GA}{t}$$

where

G is the shear modulus;
 A is the cross-sectional area;
 t is the thickness.

For soft, filler-free vulcanizates, the shear modulus is approximately one-third of the value of Young's modulus. The ratio decreases with increasing filler content and in hard rubbers can reach 1 : 4.

A test method for shear modulus is described in BS 903-A14.

3.2.4 Compression modulus. Unlike shear modulus, the compression stress-strain characteristics of a rubber component do not depend only on the rubber. A bonded or otherwise constrained component is stiffer than one able to slip. This is because rubber, although soft compared with other engineering materials, still has a very high bulk modulus and resists change in volume even under high loads.

The following equation has been derived for compressed bonded components of approximately square or circular cross section, but is only reasonably accurate when the deflection is below 10 %:

$$E_c = E_o (1 + 2S^2)$$

where

E_c is the compression modulus;
 E_o is Young's modulus;
 S is the shape factor as defined below.

The shape factor of a component is the ratio of the area of one loaded face to the total area of the sides. The shape factor, S , for a rectangular block of rubber is given by the equation:

$$S = \frac{lw}{2t(l+w)}$$

where

l is the length;
 w is the width;
 t is the thickness.

When $S > 3$, E_c is approximately equal to $5GS^2$.

A test method for compression stress-strain properties is described in BS 903-A4.

3.2.5 Tensile modulus. Although seldom suitable for design purposes, stress measurements at elongations well above the linear stress-strain region are often made during the course of tensile strength testing. They are used for quality control, and as a measure of the degree of vulcanization they are more sensitive than hardness. The test elongation is typically 100 % or 300 %, and the stress (usually referred to as "modulus") is calculated on the unstrained cross section of the test piece. Tensile stress-strain testing is described in BS 903-A2.

3.3 Strength properties

3.3.1 Tensile strength. Tensile strength is one of the most widely determined properties of rubber and is often included in specifications essentially as a measure of quality because proper component design ensures that rubbers are seldom used at or near their breaking point in tensile deformation. The value for tensile strength is expressed as the breaking force per unit area of the unstrained cross section of a test piece having the form of a dumb-bell or ring (see BS 903-A2). Expressed in this way, tensile strength for certain rubbers can be as high as 30 MPa¹⁾ and if the force is based on the cross-sectional area at break the strength can approach that of some metals, because the elongation at break of rubber can sometimes reach 1 000 %. Tensile strength varies widely with rubber type and is sensitive to compounding, passing through a maximum as crosslink density and hardness are raised. Elongation at break usually decreases with increasing stiffness.

3.3.2 Tear resistance. Tear is a localized strength failure in a material whose bulk strain is below its breaking point, and thus will be more likely to occur where there is a high stress concentration, as will be the case at a nick or sharp angle. Resistance can be improved by reinforcing fillers, but by proper design of components the conditions for premature tear failure are often avoidable. Test methods for tear strength are described in BS 903-A3 and they are used because a rubber compounded for optimum tensile strength does not always have the best tear resistance. Several types of test piece have been standardized because the property is affected by the loading conditions, an influence sufficient to change the ranking of materials.

3.3.3 Fatigue resistance. Like other materials, rubber can undergo fatigue failure as a result of crack growth and, as in the case of tear, this can occur at tensile deformations well below the breaking strain. The conditions for fatigue cracking usually involve dynamic loading in tension or flexure, but vulcanizates based on rubbers unable to strain-crystallize can also suffer from mechanical crack growth under static loading. The dependence of fatigue resistance on strain and the surrounding environment can be summarized as follows.

a) Fatigue life increases rapidly as the maximum strain imposed is reduced, and in the absence of chemical attack becomes, for all practical purposes, infinitely long once the strain falls below the “mechanical fatigue limit” characteristic of the rubber.

b) Atmospheric oxygen can reduce the fatigue limit and increase the rate of crack growth above it, the effect varying with the type of rubber and diminishing at higher frequencies and strains.

c) At strains below the “mechanico-oxidative” fatigue limit, a slow crack growth may occur as a result of ozone attack in unsaturated rubbers (see 3.5.6).

d) In strain-crystallizing rubbers, fatigue life is enhanced in components that do not return to zero strain during cycling, the resistance increasing with the minimum strain and with the ratio of the minimum strain to maximum strain. This is an important design feature and the condition exists in most well-designed rubber springs since a relatively low amplitude strain cycle is superimposed over a static load.

There are three British Standard test methods for determining the fatigue resistance of vulcanized rubber. Two are conducted in flexure, one for flex cracking resistance (BS 903-A10) and the other for crack growth resistance (BS 903-A11), but the straining conditions are fixed and the results are not really amenable for design purposes. More suitable is the tension fatigue test, described in BS 903-A51, since this allows resistance to be determined over a wide strain range and thus permits an estimate to be made of the mechanical fatigue limit.

3.4 Viscoelastic properties

3.4.1 Dynamic properties. When subjected to a forced sinusoidal motion, rubbers respond in a manner typical of viscoelastic materials, in that the resulting stress response is out of phase with the strain. The material can be characterized by any two of the following parameters:

- a) the complex modulus, G^* (or E^*), defined as the ratio of peak stress to peak strain;
- b) the in-phase modulus, G' (or E'), defined as the ratio of the amplitude of the in-phase component of stress to strain amplitude;
- c) the out-of-phase modulus, G'' (or E''), defined as the ratio of the amplitude of the out-of-phase component of stress to the strain amplitude;
- d) the phase angle, δ , defined as the phase difference between stress and strain cycles.

The relationships between these parameters are:

$$G^* = \{(G')^2 + (G'')^2\}^{0.5}$$

and

$$\tan \delta = G''/G'$$

Both complex moduli and phase angle will be functions of frequency, temperature and, for filled rubbers, the amplitude of the strain cycle.

¹⁾ 1 MPa = 1 MN/m²