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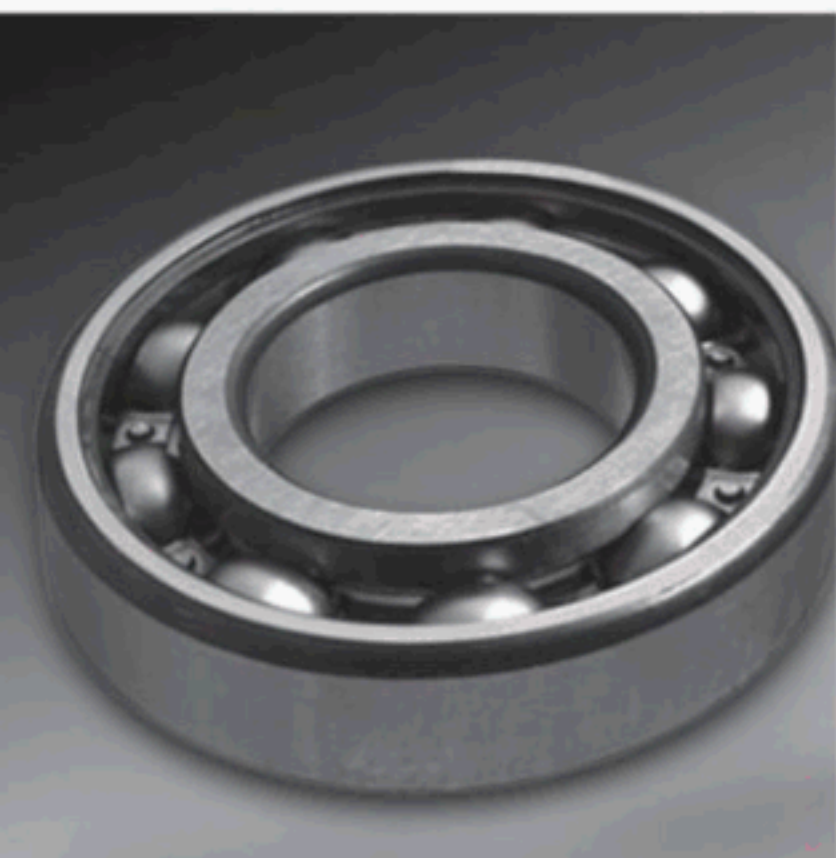
Metal Balls for Unground Bearings and Other Uses ANSI/ABMA 10A:2001 (R2015)



Secretariat

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Manufacturers Association**

ANSI/ABMA 10A:2001 (R2015)



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Metal Balls for Unground Bearings and Other Uses

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METAL BALLS FOR UNGROUND BEARINGS AND OTHER USES

1. Scope. This standard establishes the requirements for metal balls for unground rolling contact bearings and other uses. The requirements for finished balls for rolling contact bearings are contained in ANSI/ABMA/ISO 3290.

2. Normative references. The following standards contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards below.

ANSI B89.3.1-1972 (R1988), *Out-Of Roundness, Measurement of*

ANSI/ASME B46.1-1995, *Surface Texture (Surface Roughness, Waviness and Lay)*

ANSI/ASQC Z1.4- 1993, *Sampling Procedures and Tables for Inspection by Attributes*

ASTM E 18-98, *Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*

ASTM E140-97e1, *Hardness Conversion Tables for Metals (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, Knoop Hardness and Scleroscope Hardness)*

ASTM E384-89 (1997), *Standard Test Method for Microhardness of Materials*

Federal Specification GGG-G-15C (March 20, 1975), *Gage Blocks and Accessories (Inch and Metric)*

ISO 3290: 1998, *Rolling bearings - Balls - Dimensions and Hardness*

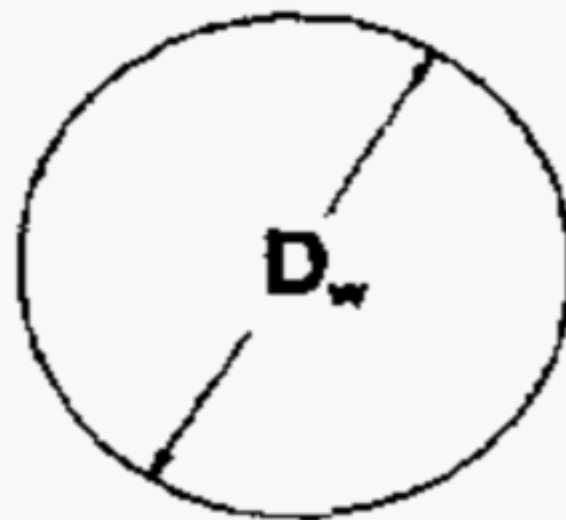
ISO 4288: 1996, *Geometrical Product Specifications (GPS) - Surface texture: Profile method - Rules and procedures for the assessment of surface texture*

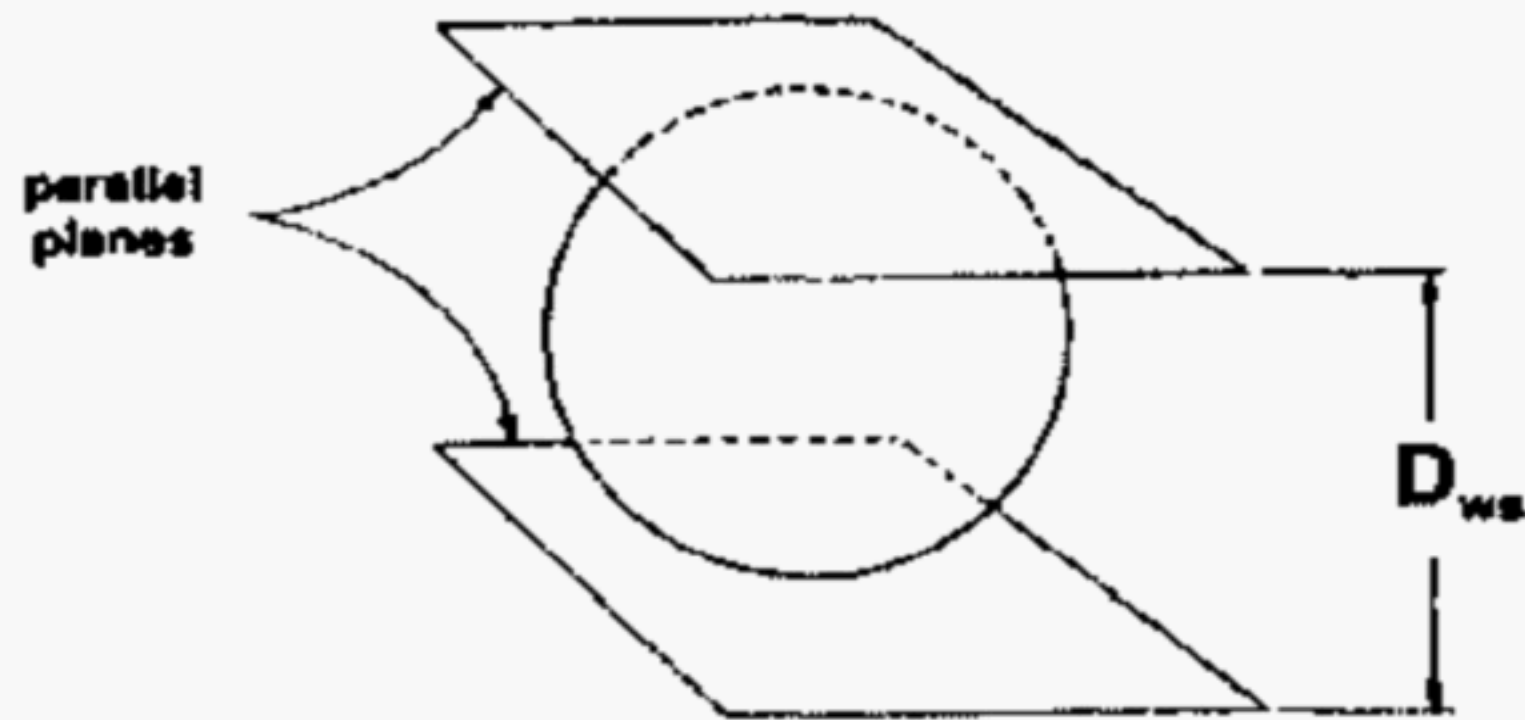
ISO 4291: 1985, *Methods for the assessment of departure from roundness - Measurement of variations in radius*

ISO 6508-1: 1999, *Metallic materials - Hardness test - Rockwell test (scales A - B - C - D - E - F - G - H - K)*

3. Definitions and symbols. The following definitions and symbols will apply to terms used in this standard.

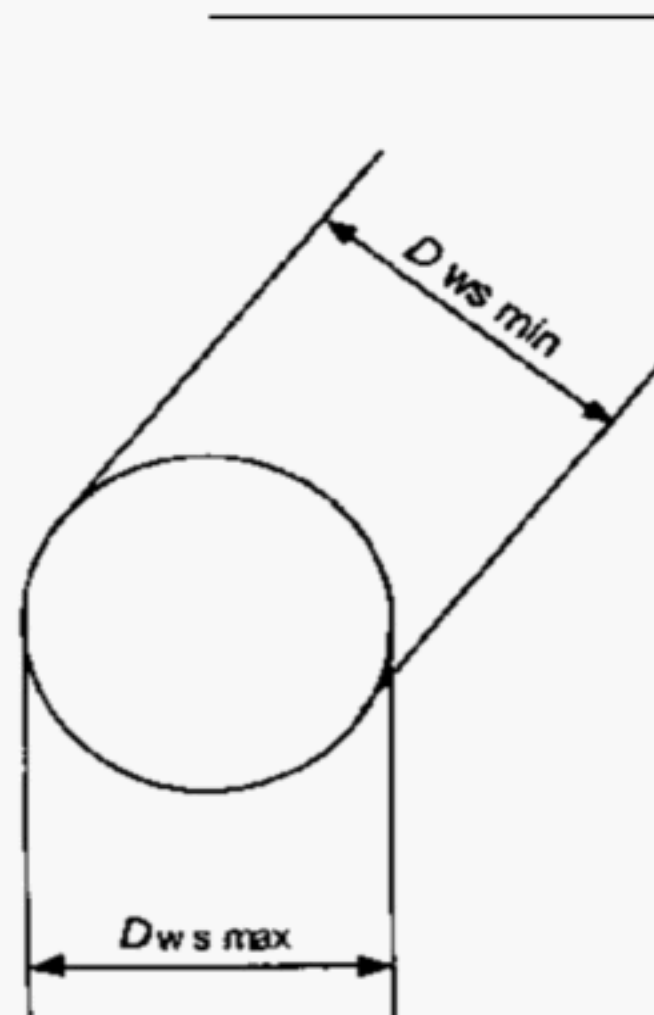
3.1 Nominal ball diameter, D_w . The diameter value that is used for the purpose of general identification of a ball size; e.g., $\frac{1}{4}$ inch, 6 mm, etc.





3.2 Single ball diameter, D_{ws} . The distance between two parallel planes tangent to the surface of a ball.

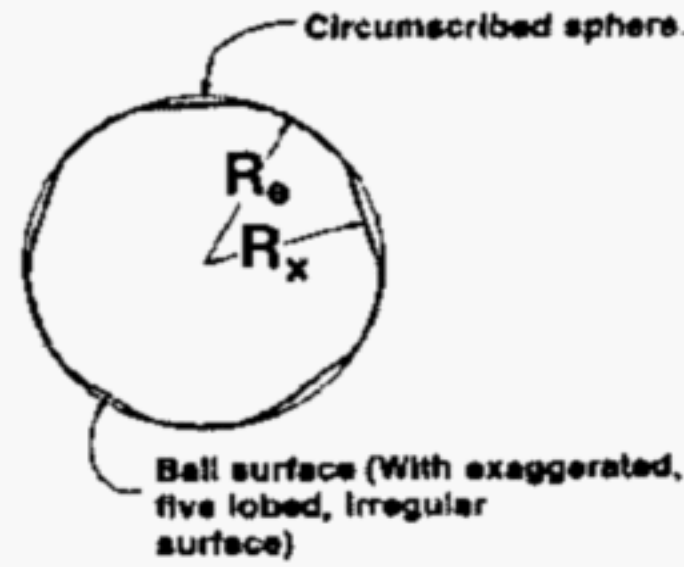
3.3 Mean ball diameter, D_{wm} . Arithmetic mean of the largest and the smallest of the single diameters of a ball.



3.4 Variation of ball diameter, V_{Dws} . Difference between the largest and the smallest of the single diameters of a ball.

$$V_{Dws} = D_{ws \max} - D_{ws \min}$$

3.5 Deviation from spherical form, ΔR_w . The greatest radial distance, in any equatorial radial plane, between the smallest circumscribed sphere and the greatest inscribed sphere with their center common to the least square sphere center.



3.6 Ball lot. Definite quantity of balls manufactured under conditions presumed uniform and which is considered as an entity.

3.7 Mean diameter of a ball lot, D_{wmL} (see figure 1). Arithmetic mean of the mean diameters of the largest ball and the smallest ball in a ball lot.

3.8 Variation of ball lot diameter, V_{DwL} (see figure 1). Difference between the mean diameters of the largest ball and the smallest ball in a ball lot.

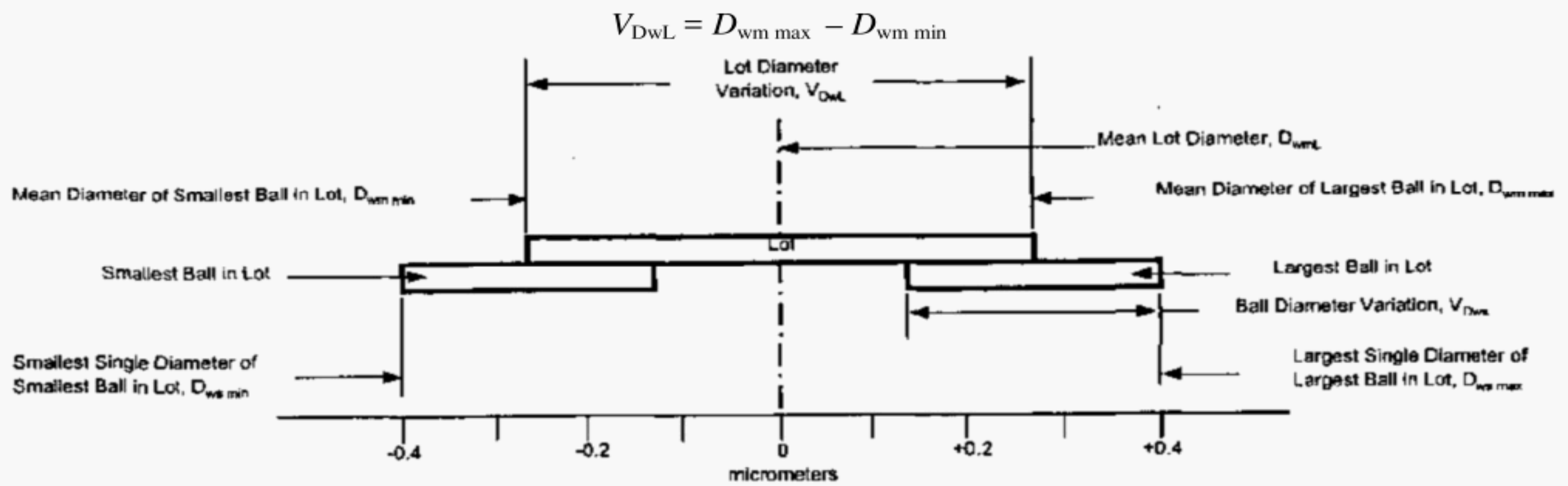


Figure 1-1 - Variation in lot of Grade 10A balls
(Metric dimensions)

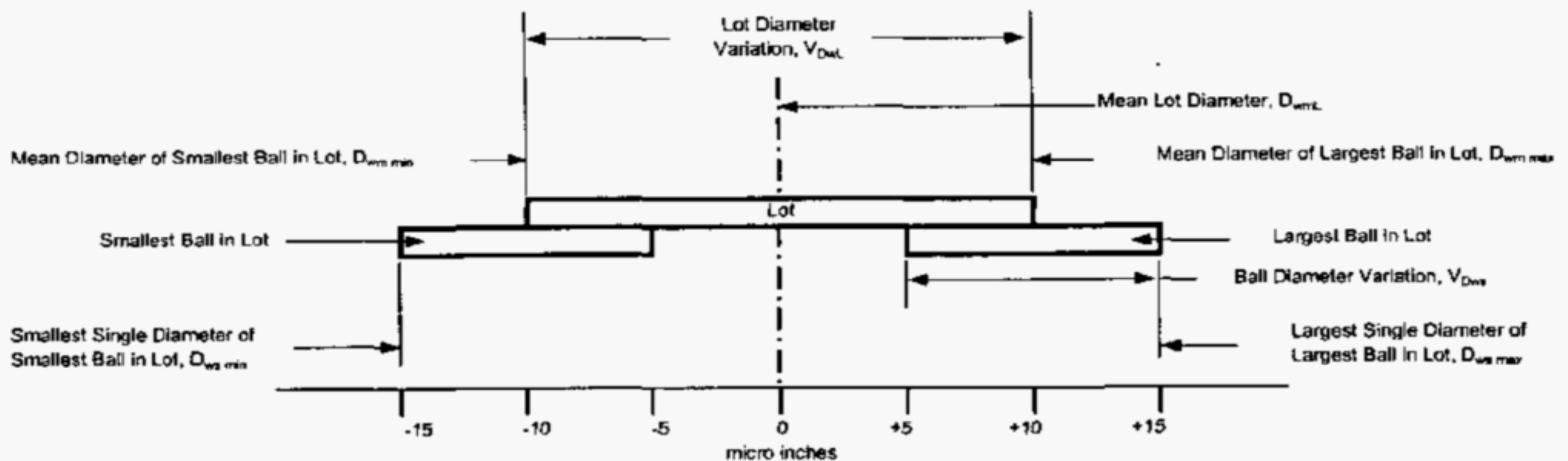


Figure 1-2 - Variation in lot of Grade 10A balls
(Inch dimensions)

3.9 Nominal ball diameter tolerance. The maximum allowable deviation of any ball lot mean diameter from the nominal ball diameter.

3.10 Ball grade, GxxA. Specific combination of dimensional, form, surface roughness and sorting tolerances for balls.

3.11 Surface roughness, R_a . Surface irregularities with relatively small spacing, which usually include irregularities resulting from the method of manufacture being used and/or other influences. Values are expressed as arithmetic averages.

3.12 Waviness. Surface irregularities of random or periodical deviation from the spherical ideal form. (Lacking standardized practices in this field, the specifications and tolerances for waviness are subject to agreement between manufacturer and purchaser.)

3.13 Hardness. The measure of resistance to penetration of the ball surface or truncated flat of the ball by a specific indenting shape as determined by specified methods.

3.14 Case depth. The distance measured radially from the surface of the ball to a point where the hardness becomes the equivalent to 50 HRC. This term is applicable to case hardened balls only.

3.15 Passivation. A chemical treatment to remove corrodible surface impurities and to provide a protective film. This term is applicable to corrosion resisting balls only.

4. Requirements

4.1 Materials. The materials listed in Table 1 are the most commonly used; however, other materials are available from individual suppliers. For typical chemical analysis and a cross reference of other applicable specifications refer to the Unified Numbering System for Metals and Alloys published by the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

4.2 Hardness. Hardness of balls manufactured of the materials in 4.1 shall be agreed between manufacturer and purchaser. Table 1 shows typical hardness values. Tempering of carbon steel balls for stress relief shall be subject to agreement between manufacturer and purchaser.

Table 1 - Commonly used material specification reference chart

MATERIAL	COMMON STANDARD	SAE UNIFIED NUMBER	TYPICAL HARDNESS (1) (2)	BALL GRADE	PREFERRED NOMINAL SIZE RANGES FOR VARIOUS GRADES	
					mm	inch
CHROME ALLOY STEEL	AISI/SAE E52100 AISI/SAE E51100	G-52986 G-51986	60 – 67 HRC (3) (5)	G3A	0.8 – 25	1/32 – 1
				G5A, G10A G16A, G24A	0.3 – 38	1/64 – 1-1/2
				G48A, G100A G200A G500A	0.8 -73	1/32 – 2-7/8
				G1000A	10 - 115	3/8 – 4-1/2
ALLOY TOOL STEEL	AISI/SAE M50 AISI/SAE T1	T-11350 T-12001	60 - 65 HRC (3) (5) 60 - 65 HRC (3) (5)	G3A, G5A G10A, G16A	0.8 -12	1/32 – 1/2
				G24A, G48A	0.8 - 40	1/32 – 1-5/8
CORROSION RESISTING HARDENED STEEL	AISI/SAE 440C AISI/SAE 440B AISI/SAE 420 AISI/SAE 410 AISI/SAE 329	S-44004 S-44003 S-42000 S-41000 S-32900	58 - 65 HRC (4) (5) 55 - 62 HRC(4) (5) 52 HRC min (4) (5) 97 HRB 41 HRC (4) (5) 45 HRC min (4) (5)	G3A, G5A, G10A, G16A	0.3 - 19	1/64 – 3/4
				G24A	0.8 - 25	1/32 – 1
				G48A	0.8 -50	1/32 – 2
				G100A, G200A	0.8 - 115	1/32 – 4-1/2
CORROSION RESISTING UNHARDENED STEEL	AISI/SAE 302 AISI/SAE 304 AISI/SAE 305 AISI/SAE 316 AISI/SAE 430	S-30200 S-30400 S-30500 S-31600 S-43000	25 - 39 HRC (5) (6) 25 - 39 HRC (5) (6) 25 - 39 HRC (5) (6) 25 - 39 HRC (5) (6) 48 - 63 HRA (5)	G100A, G200A, G500A	1.5 – 19	1/16 – 3/4
CARBON STEEL (7)	AISI/SAE 1008 AISI/SAE 1013 AISI/SAE 1018 AISI/SAE 1022 AISI/SAE 1040	G-10080 G-10130 G-10180 G-10220 G-10400	60 HRC min (2)	G100A, G200A, G500A, G1000A, G2000A	1.5 – 38	1/16 – 1 – 1/2
SILICON MOLYBDENUM STEEL	AISI/SAE S2	T-41902	52 - 60 HRC (3)	G200A	6.5 – 28	1/4 – 1 – 1/8
ALUMINUM	AA-2017	A-92017	54 - 72 HRB	G200A	1.5 – 25	1/16 – 1
ALUMINUM BRONZE	CDA-624 CDA-630	C-62400 C-63000	94 - 98 HRB	G200A	20 – 100	13/16 – 4
BRASS	CDA-260	C-26000	75 - 87 HRB	G100A, G200A, G500A, G1000A	1.5 – 19	1/16 – 3/4
BRONZE	CDA-464	C-46400	75 – 98 HRB	G200A, G500A, G1000A	1.5 – 19	1/16 – 3/4
MONEL 400	AMS-4730	N-04400	85 - 95 HRB	G100A, G200A, G500A	1.5 – 19	1/16 – 3/4
MONEL K-500	QA-N-286	N-05500	27 HRC min	G100A, G200A	1.5 – 19 1.5 – 43	1/16 – 3/4 1/16 – 1 – 11/16
TUNGSTEN CARBIDE	JIC CARBIDE CLASSIFICATION	NOT APPLICABLE	84 - 91.5 HRA	G5A G10A G16A G24A	1.2 – 12 1.2 – 19 1.2 – 25 1.2 – 32	3/64 – 1/2 3/64 – 3/4 3/64 – 1 3/64 – 1 – 1/4

Footnotes:

- (1) Rockwell hardness tests are conducted on parallel flats in accordance with ASTM E-18 unless otherwise specified.
- (2) Hardness readings taken on spherical surfaces are subject to the corrections shown in Annex D, Table D1. Hardness readings for carbon steel balls smaller than 6 mm (1/4 inch) are taken by the microhardness method or as agreed between the manufacturer and purchaser.
- (3) Hardness of balls in any one lot shall be within 3 points on Rockwell C scale.
- (4) Hardness of balls in any one lot shall be within 4 points on Rockwell C scale.
- (5) Where microhardness is used in accordance with Annex B, the Rockwell hardness values given above are converted to DPH in accordance with ASTM E140, Standard Hardness Conversion Tables for Metals.
- (6) Annealed hardness of 75 - 90 HRB is available when specified.
- (7) Choice of carbon steels up to AISI/SAE 1040 is at the manufacturer's option.

4.3 Case depth. Carbon steel balls shall be processed to provide the minimum case depths specified in Table 2, but still retain an unhardened core of approximately 1/3 or more of the ball diameter.

4.4 Quality of surface. Surface appearance of balls manufactured from the materials specified in 4.1 shall meet the requirement specified below.

4.4.1 Chrome alloy, corrosion resisting hardened, and alloy tool steel balls. These shall be free from cracks, pits, corrosion and indications of soft spots visible without magnification, except that grades G3A, G5A and G10A in sizes 3mm (1/8 inch) diameter and smaller may be inspected by microscopic examination not exceeding 10 power.

4.4.2 Corrosion resisting unhardened steel balls. These shall be free from cracks, pits, and corrosion when examined visually without magnification.

4.4.3 Carbon steel balls. These shall be free from corrosion and indications of soft spots when examined visually without magnification.

4.4.4 Silicon molybdenum steel balls. These shall be free from cracks, pits, corrosion, decarburization and soft spots when examined visually without magnification.

4.4.5 Non-ferrous metal balls. Balls of nonferrous alloys, aluminum, aluminum bronze, brass, bronze, Monel metal and K-Monel metal shall be free from cracks when examined visually without magnification.

4.4.6 Tungsten carbide balls. These shall be free from cracks when examined visually without magnification.

Table 2, Part 1 (Metric) Case depth requirements for carbon steel balls		
Dimensions in millimeters		
D_w		Minimum case depth ⁽¹⁾
\geq	$<$	
0.3	1.5	0.1
1.5	2.0	0.4
2.0	3.0	0.5
3.0	4.5	0.6
4.5	5.5	0.8
5.5	6.5	0.9
6.5	9.5	1.1
9.5	11.0	1.4
11.0	12.5	1.7
12.5	14.0	1.8
14.0	19.0	1.9
19.0	38.0	2.0

Table 2, Part 1 (Inch) Case depth requirements for carbon steel balls		
Dimensions in millimeters		
D_w		Minimum case depth ⁽¹⁾
\geq	$<$	
1/64	1/16	0.005
1/16	3/32	0.015
3/32	1/8	0.020
1/8	3/16	0.025
3/16	7/32	0.030
7/32	1/4	0.035
1/4	3/8	0.045
3/8	7/16	0.055
7/16	1/2	0.065
1/2	9/16	0.070
9/16	3/4	0.075
3/4	1-1/2	0.080

⁽¹⁾ Case depth is determined in accordance with Annex C - Recommended Procedure for the Measurement of Case Depth in Carburized and Hardened Carbon Steel Balls.

4.5 Geometric quality. Tolerances for size, form, and surface roughness are listed in Tables 3 and 4 for the various grades.

Table 3, Part 1 (Metric) Tolerances by grade by individual balls			
Tolerances in micrometers			
Ball grade	Variation of ball diameter V_{Dws}	Deviation from spherical form $\Delta R_{w \max}$	Surface roughness (arithmetic average) $R_{a \max}$
G3A	0.08	0.08	0.012
G5A	0.13	0.13	0.02
G10A	0.25	0.25	0.025
G16A	0.4	0.4	0.025
G24A	0.6	0.6	0.05
G48A	1.2	1.2	0.08
G100A	2.5	2.5	0.125
G200A	5	5	0.2
G500A	13	13	*
G1000A	25	25	*
G2000A	50	50	*

* Not specified

Table 3, Part 2 (Inch) Tolerances by grade by individual balls			
Tolerances in micro-inches			
Ball grade	Variation of ball diameter V_{Dws}	Deviation from spherical form $\Delta R_{w \max}$	Surface roughness (arithmetic average) $R_{a \max}$
G3A	3	3	0.5
G5A	5	5	0.8
G10A	10	10	1
G16A	16	16	1
G24A	24	24	2
G48A	48	48	3
G100A	100	100	5
G200A	200	200	8
G500A	500	500	*
G1000A	1000	1000	*
G2000A	2000	2000	*

Table 4, Part 1 (Metric) Tolerances by grade for lots of balls		
Tolerances in micrometers		
Ball grade	Variation of ball lot diameter $V_{dwL \max}$	Nominal ball diameter tolerance
G3A	0.13	*
G5A	0.25	*
G10A	0.5	*
G16A	0.8	*
G24A	1.2	*
G48A	2.4	*
G100A	5	±12.5
G200A	10	±25
G500A	25	±50
G1000A	50	±125
G2000A	100	±250

* Not specified

Table 4, Part 2 (Inch) Tolerances by grade for lots of balls		
Tolerances in micro-inches		
Ball grade	Variation of ball lot diameter $V_{dwL \max}$	Nominal ball diameter tolerance
G3A	5	*
G5A	10	*
G10A	20	*
G16A	32	*
G24A	48	*
G48A	96	*
G100A	200	±500
G200A	400	±1000
G500A	1000	±2000
G1000A	2000	±5000
G2000A	4000	±10,000

4.5.1 Measurement methods - size and size variation. For ball grades G3A-G200A, comparative methods shall be used. For ball grades greater than G200A, micrometers of known calibration status capable of measuring to 0.001 mm (or 0.0001 inch) may be used for determining size and variation of ball lot.

4.5.2 Masters for comparative measurements. Masters used for comparative measurements of size and variation of ball lot shall be made with masters traceable to the National Institute of Standards and Technology (NIST). The size of the master balls, or blocks shall be corrected to zero gage pressure, and to a temperature of 20°C (68°F).

4.5.2.1 Master materials. Master balls or blocks may be made of hardened chrome steel, tungsten carbide, or composite materials such as alumina oxide or zirconia. Hardness shall be 64 HRC or higher. When master balls are used for ball sizes of 1.5 mm (1/16 inch) diameter and smaller, master balls may be 440 stainless steel, 60 HRC or higher.

4.5.2.2 Master balls. The permissible diameter variation shall be one-tenth of the allowable diameter variation for the ball grade being measured, or 0.05 micrometers (2 micro-inches), whichever is larger. The calibrated diameter of the master ball is defined as the mean of at least twenty (20) randomly oriented diameters and must be known to an accuracy equal to plus or minus the magnitude of the permissible diameter variation of the master ball or plus or minus 0.08 micrometers (3 micro-inches), whichever is larger.

4.5.2.3 Master gage blocks. Master blocks used for comparative measurements shall have a known calibration status. Gage block sets shall be Grade 2, or better, as defined by Federal Specification GGG-G-15C, except as noted below. When more than one block is used for comparative measurement, proper compensation, as defined in the calibration record of the set, shall be taken for each block used in the setup.

Exception: Lower grade sets, or blocks, may be used provided the gage block deviation from nominal size is known, and proper compensation for deviation is taken during the setup, or interpretation of the measured size.

4.5.3 Gage pressures. Gage contact materials shall have at least the same hardness as the ball measured. Gage contacts must be flat, or if convex, have a contact radius not less than 3 mm or 0.125 inch. Maximum measuring pressures at gage contacts shall not exceed 1.1 newtons (4 ounces) for balls up to and including 25 mm (1 inch) nominal diameter and not exceed 2.2 newtons (8 ounces) for larger nominal diameters, including ball weight if significant.

4.5.4 Gage contact point wear. Proper care shall be exercised by the ball manufacturer to ensure that excessive wear at points of contact on any gage used for final acceptance of size and size variation is known and controlled.

4.6 Corrosion resistance. Corrosion resistant steel balls, hardened and unhardened of materials specified in Table 1 shall be subject to the following requirements.

4.6.1 Passivation. Balls shall be passivation surface treated to remove all traces of corrodible impurities.

4.6.2 Corrosion test. Finished balls shall be capable of passing the following corrosion test.

A sample of balls shall be immersed in distilled water at 38°C ± 3°C (100°F ± 5°F) for a period of one hour, followed by air drying at 38°C ± 3°C (100°F ± 5°F) for a period of one hour. This cycle shall be repeated for a total period of 24 hours.

At the end of the 24 hour period, the sample balls shall be examined for surface corrosion. No ball in the sample may exhibit corrosion visible under 10 power magnification.

5. Preferred nominal sizes by materials and grades

5.1 Preferred nominal sizes. Table 5 lists standard nominal diameter sizes in the size ranges 0.3 mm (0.0112 inch) - 114.3 mm (4.5 inches).

5.2 Preferred nominal size ranges by materials and grades. Table 1 lists preferred grades and nominal size ranges by specified materials.

**TABLE 5
PREFERRED NOMINAL BALL SIZES**

Nominal diameter D _w		Diameter	
mm	in	mm	in
0.3		0.30000	0.011810
	1/64	0.39688	0.015625
		0.40000	0.015750
		0.50000	0.019680
	0.020	0.50800	0.020000
0.6		0.60000	0.023620
	0.025	0.63500	0.025000
0.7		0.70000	0.027560
	1/32	0.79375	0.031250
0.8		0.80000	0.031496
1.0		1.00000	0.039370
	3/64	1.19063	0.046875
1.2		1.20000	0.047240
1.5		1.50000	0.059060
	1/16	1.58750	0.062500
	5/64	1.98438	0.078125
2.0		2.00000	0.078740
	3/32	2.38125	0.093750
2.5		2.50000	0.098420
	7/64	2.77812	0.109375
3.0		3.00000	0.118110
	1/8	3.17500	0.125000
3.5		3.50000	0.137900
	9/64	3.57188	0.140625
	5/32	3.96875	0.156250
4.0		4.00000	0.157480
	11/64	4.36562	0.171875
4.5		4.50000	0.177160
	3/16	4.76250	0.187500
5.0		5.00000	0.196850
5.5		5.50000	0.216540
	7/32	5.55625	0.218750
	15/64	5.95312	0.234375
6.0		6.00000	0.236220
	1/4	6.35000	0.250000
6.5		6.50000	0.255900
	17/64	6.74688	0.265625
7.0		7.00000	0.275590
	9/32	7.14375	0.281250
7.5		7.50000	0.295280
	19/64	7.54062	0.296875
	5/16	7.93750	0.312500
8.0		8.00000	0.314960
8.5		8.50000	0.334640
	11/32	8.73125	0.343750

Nominal ball diameter D _w		Diameter	
mm	in	mm	in
9.0		9.00000	0.354330
	23/64	9.12812	0.359375
	3/8	9.52500	0.375000
	25/64	9.92187	0.390625
10.0		10.00000	0.393700
	13/32	10.31875	0.406250
11.0		11.00000	0.433070
	7/16	11.11250	0.437500
11.5		11.50000	0.452756
	29/64	11.50938	0.453125
	15/32	11.90625	0.468750
12.0		12.00000	0.472440
	31/64	12.30312	0.484375
	1/2	12.70000	0.500000
13.0		13.00000	0.511810
	17/32	13.49375	0.531250
14.0		14.00000	0.551180
	9/16	14.28750	0.562500
15.0		15.00000	0.590550
	19/32	15.08125	0.593750
	5/8	15.87500	0.625000
16.0		16.00000	0.629920
	21/32	16.66875	0.656250
17.0		17.00000	0.669290
	11/16	17.46250	0.687500
18.0		18.00000	0.708660
	23/32	18.25625	0.718750
19.0		19.00000	0.748030
	3/4	19.05000	0.750000
	25/32	19.84375	0.781250
20.0		20.00000	0.787400
	13/16	20.63750	0.812500
21.0		21.00000	0.826770
	27/32	21.43125	0.843750
22.0		22.00000	0.866140
	7/8	22.22500	0.875000
23.0		23.00000	0.905510
	29/32	23.01875	0.906250
	15/16	23.81250	0.937500
24.0		24.00000	0.944880
	31/32	24.60625	0.968750
25.0		25.00000	0.984250
	1	25.40000	1.000000
26.0		26.00000	1.023620

TABLE 5 (continued)
PREFERRED NOMINAL BALL SIZES

Nominal ball diameter D_w		Diameter	
mm	in	mm	in
28	1-1/16	26.98750	1.062500
		28.00000	1.102360
30	1-1/8	28.57500	1.125000
		30.00000	1.181100
	1-3/16	30.16250	1.187500
32	1-1/4	31.75000	1.250000
		32.00000	1.259840
34	1-5/16	33.33750	1.312500
		34.00000	1.338580
35	1-3/8	34.92500	1.375000
		35.00000	1.496060
		36.00000	1.417320
38	1-7/16	36.51250	1.437500
		38.00000	1.496060
	1-1/2	38.10000	1.500000
40	1-9/16	39.68750	1.562500
		40.00000	1.574800
	1-5/8	41.27500	1.625000
45	1-11/16	42.86250	1.687500
	1-3/4	44.45000	1.750000
		45.00000	1.771650
50	1-13/16	46.03750	1.812500
	1-7/8	47.62500	1.875000
	1-15/16	49.21250	1.937500
55		50.00000	1.968500
	2	50.80000	2.000000
	2-1/8	53.97500	2.125000
60		55.00000	2.165354
	2-1/4	57.15000	2.250000
		60.00000	2.559055
65	2-3/8	60.32500	2.375000
	2-1/2	63.50000	2.500000
		65.00000	2.559055
	2-5/8	66.67500	2.625000
	2-3/4	69.85000	2.750000
	2-7/8	73.02500	2.875000
	3	76.20000	3.000000
	3-1/8	79.37500	3.125000
	3-1/4	82.55000	3.250000
	3-3/8	85.72500	3.375000
	3-1/2	88.90000	3.500000
	3-5/8	92.07500	3.625000
	3-3/4	95.25000	3.750000
	3-7/8	98.42500	3.875000
	4	101.60000	4.000000
	4-1/8	104.77500	4.125000
	4-1/4	107.95000	4.250000
	4-3/8	111.12500	4.375000
	4-1/2	114.30000	4.500000

6. Quality assurance provisions

6.1 Grades G3A-G24A inclusive. These ball grades are not generally applicable to balls for unground ball bearings. Unless otherwise required, the product shall meet the acceptance inspection, as required by ANSI/ASQC Z1.4, as stipulated in Table 6

Table 6 - Applicable inspection levels and acceptance quality level (AQL)

Requirement	Applicable clause	Inspection level	AQL
Quality of geometry	6.3.1 6.3.2 6.3.3	S4 ⁽¹⁾	0.4 %
Quality of surface	6.3.5	S4	0.4 %
Surface roughness	6.3.4	Use sample size shown below and accept if all test results are within specifications	
Hardness	6.3.6		
Surface corrosion and decarburization	6.3.7		
Case depth (when applicable)	6.3.8	Number of balls	Sample size
		0 – 35, 000	5
		35, 001 and over	8

⁽¹⁾ Minimum sample size of 32 balls shall apply only to lots of 1200 or more balls. For lots of less than 1200 balls, sample size shall be set by agreement between manufacturer and purchaser.

6.2 Grades G48A-G2000A. Quality assurance provisions for these grades are not standardized and shall be subject to agreement between manufacturer and purchaser.

6.3 Methods of inspection. All inspection operations shall be carried out in an environment suitable for the grades furnished, by skilled personnel, and with equipment of accuracy and magnification suitable for the various operations required by this standard, as enumerated in Section 4, and in accordance with Table 6, where applicable.

6.3.1 Variation of ball diameter, V_{Dws} . Measure and record the largest and the smallest diameter of each ball in the sample and compute the variation of each ball. Record the largest variation found on any one ball. Compute in accordance with 3.4

6.3.2 Variation of ball lot diameter, V_{DwL} . Using the information obtained from 6.3.1, compute the mean diameter of the largest ball in the sample and that of the smallest ball. Compute and record the lot diameter variation in accordance with 3.8.

6.3.3 Deviation from spherical form. Pending further standardization of methods, the use of either of the methods specified in Appendix A is permissible.

6.3.4 Surface roughness. For those grades where surface roughness requirements apply, measurements shall be made on equipment meeting the requirements of, and in accordance with ANSI/ASME B46.1 or ISO 4288, as agreed between manufacturer and purchaser.

6.3.5 Surface appearance. Examination shall be conducted in accordance with the requirements of 4.4 for the material specified.

6.3.6 Hardness. Ball diameters up to, but not including, 5 mm (3/16 inch) shall be subjected to microhardness testing. Microhardness measurements shall be made in accordance with ASTM E384. Additional recommendations for microhardness testing of balls are given in Annex B.

Hardness of balls 5 mm (3/16 inch) and larger in diameter shall be tested on the HRC scale Rockwell hardness measurements shall be made in accordance with ASTM E18 or ISO 6508. Ball hardness numbers, as measured on the HRC scale, are subject to the correction factors in Annex D.

As an alternate method for carbon steel balls 3 mm (1/8 inch) to 6 mm (1/4 inch) in diameter, hardness may be measured on the HR30N scale.

As an alternate method for 3 mm (1/8 inch) and larger balls made of corrosion resisting unhardened steel, aluminum, aluminum bronze, brass, bronze, Monel, and K-Monel, hardness may be measured using a superficial hardness test.

6.3.7 Surface corrosion. The appropriate visual examination for balls of the various materials as stated in 4.4 shall be conducted using no magnification or microscopic inspection except as noted in 4.4.1.

6.3.8 Case depth. Measurement of case depth in carburized and hardened carbon steel balls shall be conducted in accordance with Annex C.

7. Ordering specifications and package marking

7.1 Ordering specifications. Unless otherwise agreed between producer and user, orders for balls shall provide the following information:

- Quantity
- Material
- Nominal ball diameter
- Grade

7.1.2 Example of order. The following example illustrates usual ordering specifications:

Metric

- 80,000 pieces
- Chrome alloy steel
- 6 mm nominal diameter
- Grade G16A

Inch

- 80,000 pieces
- Chrome alloy steel
- 1/4 inch nominal diameter
- Grade G16A

7.2 Package marking. The ball manufacturer or supplier shall identify packages with the information provided on the order as covered in 7.1.

7.2.1 Example of package marked in metric units. The 6-mm balls supplied to the order illustrated in 7.1.2 would have each package marked

- 5,000 balls
- Chrome alloy steel
- 6 mm nominal diameter
- Grade G16A

7.2.2 Example of package marking in inch units. The $\frac{1}{4}$ inch balls supplied to the order illustrated in 7.1.2 would have each package marked:

5,000 balls
Chrome alloy steel
 $\frac{1}{4}$ inch nominal diameter
Grade G16A

Annex A - Measurement of deviation from spherical form

(Informational)

A1 General Deviation from spherical form on finished metal balls may occur in the form of two or more almost equally spaced waves around equatorial profiles. For balls having two waves or higher orders of even numbers of waves, the measurement of single diameters of the balls may be an adequate measure provided several equatorial profiles are subjected to measurement. However, as is most usual, odd numbers of waves of considerable magnitude may also be present which cannot be fully detected by simple two point measurements.

Because of the wide range of nominal diameters, from 0.3 mm (0.0112 inch) to 114.3 mm (4½ inches), measurement of these errors of form can be a slow and difficult process, particularly on the smaller sizes of balls. Two basic methods for detecting errors of spherical form are in use. The more recently developed involves the use of specially designed, highly precise equipment generally identified by the term "Roundness Measuring Equipment." Older equipment, still in common use today for the larger sizes of balls, involves the use of "Vee blocks" and associated linear comparators of appropriate magnification.

Since metal balls are essentially quite uniform as to errors of form in any one lot, it is considered sufficient to explore not more than three profiles in three equatorial planes each oriented approximately 90° from the other on individual balls of the sample.

A1.1 Method using roundness measuring equipment

Two basic designs of roundness measuring equipment are in use today. One design operates on the basis of stylus and associated linear transducer rotating around the ball in contact with its surface, the other involves the rotation of the ball against a similar linear transducer. The extremely small motions of the stylus are, in both designs, suitably amplified and recorded on a polar chart which discloses the shape in the form of the number and extent of the waves but with radial deviations greatly magnified. The overall accuracy of the rotating spindle and associated amplifying and recording equipment must be very high, in the order of 0.025 micrometers or one (1) micro-inch. Extreme care must be taken in the interpretation of the polar charts. ISO 4291 and ANSI B89.3.1 describe several methods of chart interpretation. For finished metal balls, the minimum circumscribed circle (MCC) method is considered adequate.

A1.2 Method using Vee blocks

For the larger sizes of balls, it is practical to use Vee blocks having specific included angles and associated linear comparators or dial indicators of magnification appropriate for the grade of ball being measured. Figure A1 illustrates the proper use of this type of equipment. This equipment is useful for detecting odd numbers of waves, but no one Vee angle is adequate for the determination of all such odd orders of waves. The most desirable angles for wave numbers up to 21 appear to be 90° and 120°.

The magnification factors for the ratio of the indicator reading to the wave height or deviation from spherical form are shown in Table A1. In certain cases, combinations of Vee angles and numbers of waves present will show little or no indication - these are indicated by asterisks (*) - and such readings should be disregarded. If the number of waves is known, the deviation from spherical form is obtained by dividing the indicator reading by the appropriate factor taken from this table.

If, as is usual, the number of waves is unknown, readings should be taken on the three equatorial planes at 90° to each other, first on a simple two point gage and then successively using the 90° and the 120° Vee blocks. The deviation from spherical form is the highest of these three types of readings divided by two.

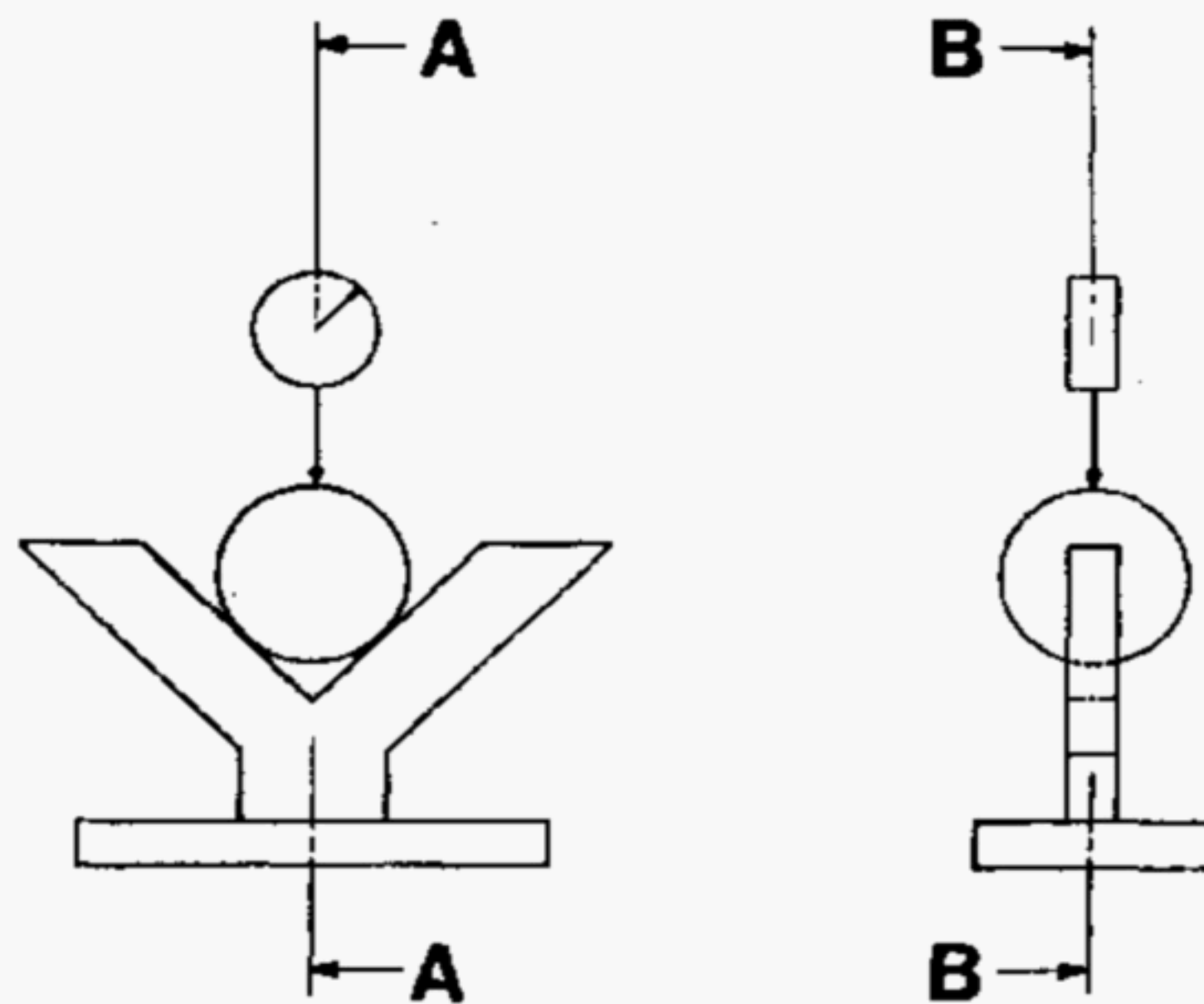


Figure A1 - Vee block

The point of stylus/ball contact must be on Axis A--A which is the bisector of the Vee block angle and Axis B--B which is the axis of the ball; also the spindle of the indicator must be in alignment with Axes A--A and B--B.

Table A1 - Magnification factor

Vee block angle	Number of waves									
	3	5	7	9	11	13	15	17	19	21
	Magnification Factor									
90°	2	2	*	*	2	2	*	*	2	2
120°	1	2	2	1	*	*	2	2	2	1

* Not desirable

Annex B - Recommended procedure for microhardness testing of small balls
(Informational)

B1 Scope. This procedure is recommended for use on balls smaller than 5 mm (3/16 inch) in nominal diameter.

B2 Specimen preparation. The balls shall be mounted in a suitable plastic material such as Bakelite, Styrene, filled or unfilled epoxy, etc.

Mounted balls shall be ground and polished, using metallographic techniques so as to present a cross section approximately 1/4 of the ball radius from the ball center, or approximately 0.25 mm (0.010 inch) from the ball center, whichever is the lesser. See the illustration below.

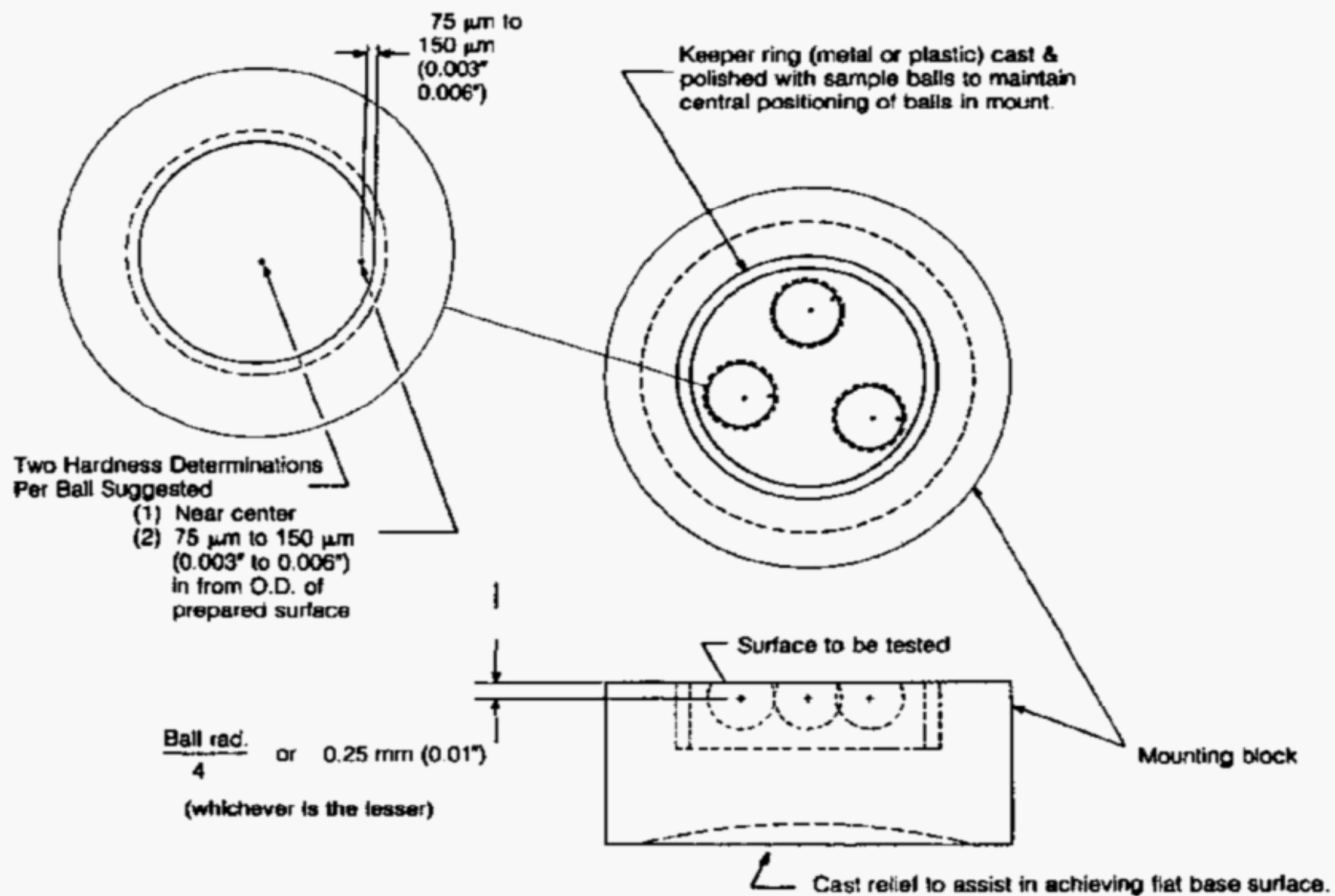


Figure B1 - Recommended method of mounting miniature balls for microhardness testing

B3 Microhardness testing.

B3.1 General. A minimum of two hardness determinations per ball shall be made, one near the center of the prepared surface and one on the same surface at a distance of from 75 to 150 micrometers (0.003 inches to 0.006 inches) from the edge of the prepared surface.

Note: On low-carbon steel balls, the core hardness and the hardness just below the surface will be different.

B3.2 Vickers hardness. A test load of 1kg (force) (9.80665 N) is recommended for all determinations except that in the size range of 1.2 mm (3/64 inch) and smaller where a 0.3 kg (force) (2.942 N) load may be required to remain within the adhesion limits of the specimen to the plastic mounting material. Extremely small diameters may require test loads of less than 0.3 kg (force) (2.942N), but it must be pointed out that a clean laboratory environment must be assured.

All hardness determinations shall be reported in DPH values including the test load, e.g., if a hardness determination of 700 DPH is indicated, employing a 0.3 kg (force) (2.942 N) test load, the hardness to be completely defined, shall be reported as 700 DPH [0.3 kg (force) load].

B3.3 Knoop hardness. A test load of 0.5 kg (force) (4.9033 N) is recommended for all determinations. All hardness determinations shall be reported in HK values.

B4 Reported hardness. The hardness level of a batch of balls shall be the arithmetic average of all hardness determinations taken on the sample of any given lot. The manufacturer's records shall show the total range of all hardness determinations taken on the sample.

Note: For low-carbon steel balls, core hardness and case hardness need to be recorded and averaged separately.

B5 Hardness conversions. There is no generally accepted method for accurate conversion of Knoop (KH) or Vickers (DPH) hardness numbers to other hardness scales.

Conversions of DPH hardness values to any other hardness system shall be interpreted only as approximations. The accepted reference for conversions shall be ASTM E140.

**Annex C - Recommended procedure for measurement
of case depth in carburized and hardened carbon steel balls**
(Informational)

C1 Scope. These procedures are used to measure the effective case depth of carburized and hardened carbon steel balls. Effective case depth is defined as the depth radially below the finished ball surface where the hardness becomes equivalent to 50 HRC.

C2 Microstructure examination

C2.1 General description. The practical method of measuring effective case depth is by means of microscopic examination of a polished and etched sample of balls prepared a suitable plastic mount. The depth is read to the transition point between the case and core where the effective case depth corresponds to the hardness equivalent of 50 HRC. The case depth is read by the microscopic method using a 20X binocular microscope fitted with a calibrated scale in the eyepiece. Higher magnifications may be used if it is necessary to more clearly define the transition zone.

C2.2 Test procedure

- (a) Mount balls in a suitable plastic material and cut or grind them to approximately one-half their diameter.
- (b) Polish for microstructure examination and etch the specimen using a 2% nital etch solution and rinse thoroughly after etch with alcohol.
- (c) Read the case depth on each ball. Case depth is measured using a calibrated eyepiece, employing binocular microscope of 20X power.
- (d) The case depth is measured radially and includes the entire transition zone from the case up to the core. Greater magnification is acceptable if it is necessary to more clearly define the transition zone.
- (e) The readings are then recorded. (See Figure C1 for an example form.)
- (f) The range in effective case depth in any lot of balls is the difference in the maximum and minimum readings observed on the entire sample inspected.

C3 Macrostructure examination

C3.1 General description. An alternate method of measuring effective case depth is by means of macrostructure examination of the fracture grain structure of a sample of balls. The depth is read to the transition point between the case and core where the effective case depth corresponds to the hardness equivalent of 50 HRC. The case depth is read by the microscopic method using a 20X binocular microscope fitted with a calibrated scale in the eyepiece. Higher magnifications may be used if it is necessary to more clearly define the transition zone.

C3.2 Test procedure

C3.2.1 Macrostructure examination.

- (a) Mount three balls vertically in a suitable fixture.
- (b) With a press or similar device, gradually apply a downward force on the stack of balls.
- (c) Applying force will cause the middle ball to break approximately in half.
- (d) Remove the balls from the fixture and discard the top and bottom balls from the stack.
- (e) Read the case depth on each half ball. Case depth is measured using a calibrated eyepiece, employing binocular microscope of 20X power. Observe the difference in the fracture grain structure of the hardened case and the softer core.^{1,2} The case depth is measured radially and includes the entire transition zone from the case up to the core. Greater magnification is acceptable if it is necessary to more clearly define the transition zone.
- (f) The readings are then recorded.
- (g) The range in effective case depth in any lot of balls is the difference in the maximum and minimum readings observed on the entire sample inspected.

¹ Howard E. Boyer, ed. Case Hardening of Steels (Metals Park, OH: ASM International, 1987), pg. 251

² Karl-Erik Thelning, Steel and Its Heat treatment, 2nd edition (London: Butterworths, 1984), pg. 445

C4 Microhardness examination.

C4.1 General description. The microhardness test is used only for referee determination of case depth and range of case depth within a lot and consists in plotting hardness values taken radially at 0.125 mm (0.005 inch) increments on a suitable graph, from which the depth at equivalent 50 HRC may be read.

C4.2 Test procedure

- (a) Use the same mounted balls that were used for the microstructure examination.
- (b) Select two (2) balls that have the minimum and maximum visual case depth.
- (c) Make microhardness readings on a radial traverse of the ball at 0.125 mm (0.005 inch) intervals starting at the transition zone nearest to the outside of the ball and continuing toward the center until at least two readings are taken that are approximately the same.
- (d) These readings are plotted on a suitable plot sheet (see Figures C2.1 and C2.2 for examples) and a line drawn to fit these plotted readings.
- (e) The effective case depth is the reading at which the line reaches 50 HRC.
- (f) The range in effective case depth in any lot of balls is the difference in case depth by microhardness readings observed in the two (2) balls that had the minimum and maximum visual case depth.
- (g) Minimum case depth values are as shown in Table 2.

Figure C1 - Case depth microstructure examination - Example record of readings*

Ball size _____ Spec. _____ Heat No. _____ Lot No. _____

Furnace No. _____ Operator _____ Time _____ Date _____

4 Samples, 5 Balls Each				
	Depth	Depth	Depth	Depth
1				
2				
3				
4				
5				
Total				
X				
R				

$\bar{X} =$ _____

$\bar{R} =$ _____

*Referred to in C2.2.1(d)

Figure C2.1 - Case depth microhardness examination - Example plot sheet (mm)

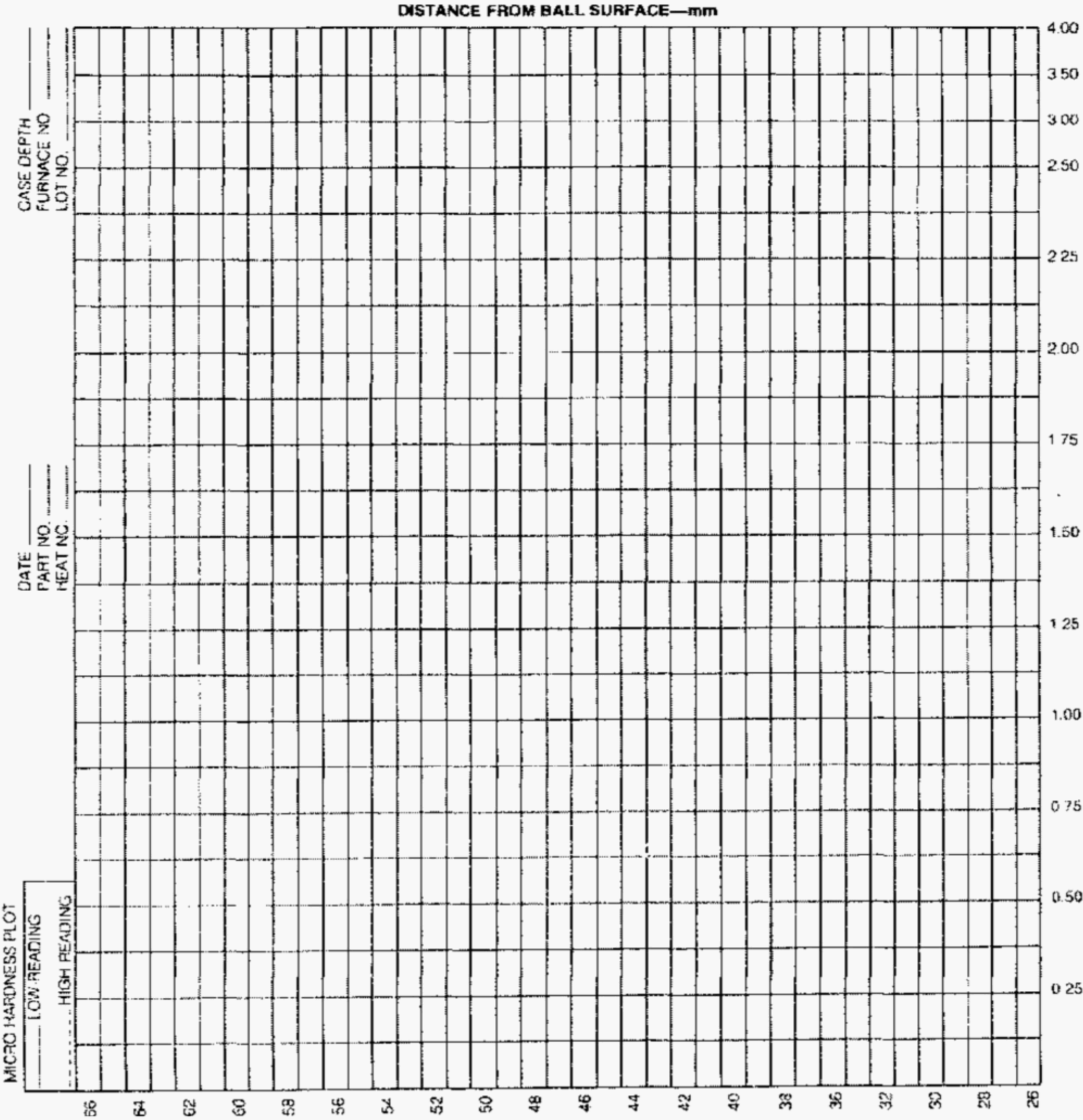
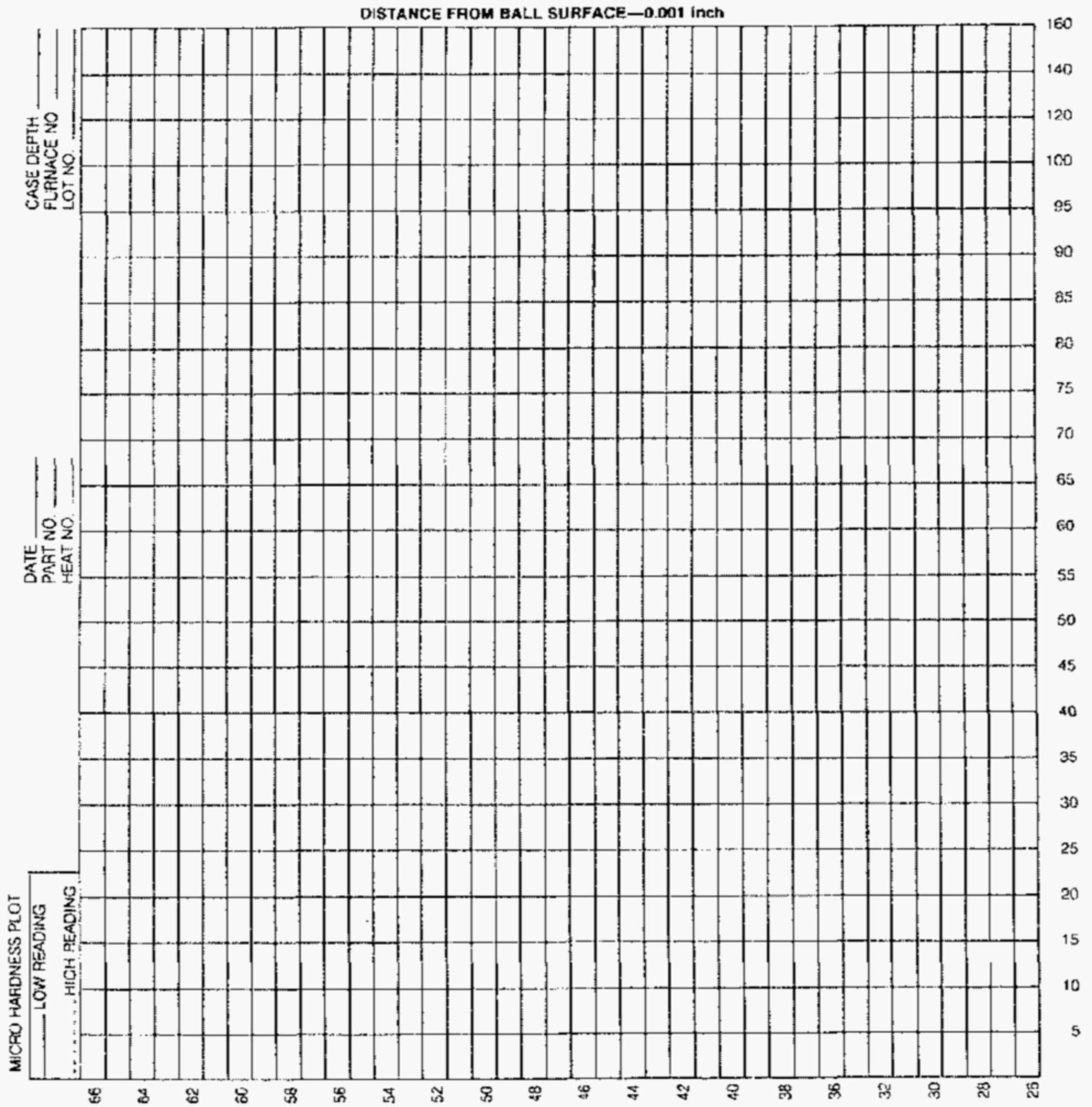


Table C2.2 - Case depth microhardness examination - Example plot sheet (inch)



Annex D - Corrections for hardness readings taken on spherical surfaces
(Normative)

D1 General. Hardness readings of balls taken on spherical surfaces are affected by the curvature and hardness level of the ball. Because of these factors, corrections are necessarily added to the as-read hardness. Table D1 below shall be applied for converting Rockwell C scale readings taken on ball surfaces to equivalent values applicable to flat surfaces.

Table D1 - Ball hardness corrections for curvatures

Corrections to be added to a Rockwell C reading obtained on spherical surfaces

Rockwell Hardness Reading	Ball diameter								
	5 mm	6.5 mm	8 mm	9.5 mm	11 mm	12.5 mm	15 mm	20 mm	25 mm
55 HRC	5.1	3.9	3.2	2.7	2.3	2	1.7	1.3	1
60 HRC	4.6	3.6	2.9	2.4	2.1	1.8	1.5	1.2	0.9
65 HRC	4.2	3.2	2.6	2.2	1.9	1.7	1.4	1	0.8

Rockwell Hardness Reading	Ball diameter								
	3/16 in	¼ in	5/16 in	3/8 in	7/16 in	½ in	5/8 in	¾ in	1 in
55 HRC	5.3	4.0	3.2	2.7	2.3	2	1.6	1.3	1
60 HRC	4.8	3.6	2.9	2.4	2.1	1.8	1.4	1.2	0.9
65 HRC	4.4	3.3	2.6	2.2	1.9	1.6	1.3	1.1	0.8

The values of the correction to be added to Rockwell hardness C scale, H, given in Table D1, are calculated using the following formulas:

a) for metric sizes:

$$\Delta H = 59 \times \frac{\left(1 - \frac{H}{160}\right)^2}{D}$$

where

H is the Rockwell hardness reading; and

D is the diameter of the ball, expressed in millimeters

b) for inch sizes:

$$\Delta H = 2.32 \times \frac{\left(1 - \frac{H}{160}\right)^2}{D}$$

where

H is the Rockwell hardness reading; and

D is the diameter of the ball, expressed in inches.

Annex E - Density, quantity and weight of common ball materials
(Informational)

Table E1 - Density of common ball materials

Material	Density	
	Grams per cubic centimeter	Pounds per cubic inch
Steel	7.833	0.283
Chrome Alloy	7.667	0.277
Corrosion Resisting Hardened	7.723	0.279
AISI M-50		
Corrosion Resisting Unhardened		
AISI 302	7.916	0.286
AISI 316	7.972	0.288
Silicon Molybdenum	7.723	0.279
Carbon Steel	7.861	0.284
Aluminum	2.796	0.101
Aluminum Bronze	7.584	0.274
Beryllium Copper	8.332	0.301
Brass	8.470	0.306
Bronze	8.415	0.304
Monel Metal	8.830	0.319
K-Monel Metal	8.470	0.306
Tungsten Carbide	14.947	0.540

For quantity of balls per kilogram or pound or weight of balls per thousand, see tables E2 and E3.

Table E2.1 - Number of balls per kilogram

NOM DIA mm	MATERIAL DENSITY IN GRAMS PER CUBIC CENTIMETER												
	2.796	7.584	7.667	7.723	7.833	7.861	7.916	7.972	8.332	8.415	8.470	8.830	14.947
0.3	25,300,000	9,330,000	9,230,000	9,160,000	9,030,000	9,000,000	8,940,000	8,870,000	8,490,000	8,410,000	8,350,000	8,010,000	4,730,000
0.4	10,670,000	3,930,000	3,890,000	3,860,000	3,810,000	3,800,000	3,770,000	3,740,000	3,580,000	3,550,000	3,520,000	3,380,000	2,000,000
0.5	5,470,000	2,010,000	1,990,000	1,980,000	1,950,000	1,940,000	1,930,000	1,920,000	1,830,000	1,820,000	1,800,000	1,730,000	1,020,000
0.7	1,990,000	734,000	726,000	721,000	711,000	708,000	703,000	698,000	668,000	662,000	657,000	631,000	373,000
0.8	1,330,000	492,000	487,000	483,000	476,000	475,000	471,000	468,000	448,000	443,000	440,000	422,000	250,000
1.0	683,000	252,000	249,000	247,000	244,000	243,000	241,000	240,000	229,000	227,000	225,000	216,000	128,000
1.2	395,000	146,000	144,000	143,000	141,000	141,000	140,000	139,000	133,000	131,000	130,000	125,000	73,900
1.5	202,000	74,600	73,800	73,300	72,200	72,000	71,500	71,000	67,900	67,200	66,800	64,100	37,900
2.0	85,400	31,500	31,100	30,900	30,500	30,400	30,200	29,900	28,700	28,400	28,200	27,000	16,000
2.5	43,700	16,100	15,900	15,800	15,600	15,500	15,400	15,300	14,700	14,500	14,400	13,800	8,180
3.0	25,300	9,330	9,230	9,160	9,030	9,000	8,940	8,870	8,490	8,410	8,350	8,010	4,730
3.5	15,900	5,870	5,810	5,770	5,690	5,670	5,630	5,590	5,350	5,290	5,260	5,040	2,980
4.0	10,700	3,930	3,890	3,860	3,810	3,800	3,770	3,740	3,580	3,550	3,520	3,380	2,000
4.5	7,500	2,760	2,730	2,710	2,680	2,670	2,650	2,630	2,520	2,490	2,470	2,370	1,400
5.0	5,470	2,010	1,990	1,980	1,950	1,940	1,930	1,920	1,830	1,820	1,800	1,730	1,020
5.5	4,110	1,510	1,500	1,490	1,470	1,460	1,450	1,440	1,380	1,360	1,360	1,300	768
6.0	3,160	1,170	1,150	1,140	1,130	1,120	1,120	1,110	1,060	1,050	1,040	1,000	592
6.5	2,490	917	907	901	888	885	878	872	835	826	821	788	465
7.0	1,990	734	726	721	711	708	703	698	668	662	657	631	373
7.5	1,620	597	590	586	578	576	572	568	543	538	534	513	303
8.0	1,330	492	487	483	476	475	471	468	448	443	440	422	250
8.5	1,110	410	406	403	397	396	393	390	373	370	367	352	208
9.0	937	345	342	339	334	333	331	329	314	311	309	297	175
10.0	683	252	249	247	244	243	241	240	229	227	225	216	128
11.0	513.0	189.0	187.0	186.0	183.0	183.0	181.0	180.0	172.0	171.0	169.0	163.0	96.0
11.5	449.0	166.0	164.0	163.0	160.0	160.0	159.0	158.0	151.0	149.0	148.0	142.0	94.0
12.0	395.0	146.0	144.0	143.0	141.0	141.0	140.0	139.0	133.0	131.0	130.0	125.0	73.9
13.0	311.0	115.0	113.0	113.0	111.0	111.0	110.0	109.0	104.0	103.0	103.0	98.5	58.2
14.0	249.0	91.8	90.8	90.1	88.9	88.5	87.9	87.3	83.5	82.7	82.2	78.8	46.6
15.0	202.0	74.6	73.8	73.3	72.2	72.0	71.5	71.0	67.9	67.2	66.8	64.1	37.9
16.0	167.0	61.5	60.8	60.4	59.5	59.3	58.9	58.5	56.0	55.4	55.1	52.8	31.2
17.0	139.0	51.3	50.7	50.3	49.6	49.5	49.1	48.8	46.7	46.2	45.9	44.0	26.0
18.0	117.0	43.2	42.7	42.4	41.8	41.7	41.4	41.1	39.3	38.9	38.7	37.1	21.9
19.0	99.6	36.7	36.3	36.1	35.5	35.4	35.2	34.9	33.4	33.1	32.9	31.5	18.6
20.0	85.4	31.5	31.1	30.9	30.5	30.4	30.2	29.9	28.7	28.4	28.2	27.0	16.0
21.0	73.8	27.2	26.9	26.7	26.3	26.2	26.1	25.9	24.8	24.5	24.3	23.4	13.8
22.0	64.2	23.6	23.4	23.2	22.9	22.8	22.7	22.5	21.5	21.3	21.2	20.3	12.0
23.0	56.1	20.7	20.5	20.3	20.0	20.0	19.8	19.7	18.8	18.7	18.5	17.8	10.5
24.0	49.40	18.20	18.00	17.90	17.60	17.60	17.50	17.30	16.60	16.40	16.30	15.60	9.24
25.0	43.70	16.10	15.90	15.80	15.60	15.50	15.40	15.30	14.70	14.50	14.40	13.80	8.18
26.0	38.90	14.30	14.20	14.10	13.90	13.80	13.70	13.60	13.00	12.90	12.80	12.30	7.27
28.0	31.10	11.50	11.30	11.30	11.10	11.10	11.00	10.90	10.40	10.30	10.30	9.85	5.82
30.0	25.30	9.33	9.23	9.16	9.03	9.00	8.94	8.87	8.49	8.41	8.35	8.01	4.73
32.0	20.80	7.68	7.60	7.55	7.44	7.41	7.36	7.31	7.00	6.93	6.88	6.60	3.90
34.0	17.40	6.41	6.34	6.29	6.20	6.18	6.14	6.10	5.83	5.77	5.74	5.50	3.25
36.0	14.60	5.40	5.34	5.30	5.23	5.21	5.17	5.13	4.91	4.86	4.83	4.64	2.74
38.0	12.40	4.59	4.54	4.51	4.44	4.43	4.40	4.37	4.18	4.14	4.11	3.94	2.33
40.0	10.70	3.93	3.89	3.86	3.81	3.80	3.77	3.74	3.58	3.55	3.52	3.38	2.00
45.0	7.50	2.76	2.73	2.71	2.68	2.67	2.65	2.63	2.52	2.49	2.47	2.37	1.40
50.0	5.47	2.01	1.99	1.98	1.95	1.94	1.93	1.92	1.83	1.82	1.80	1.73	1.02
55.0	4.110	1.510	1.500	1.490	1.470	1.460	1.450	1.440	1.380	1.360	1.360	1.300	0.768
60.0	3.160	1.170	1.150	1.140	1.130	1.120	1.120	1.110	1.060	1.050	1.040	1.000	0.592
65.0	2.490	0.917	0.907	0.901	1.888	0.885	0.878	0.872	0.835	0.826	0.821	0.788	0.465

For Density of Ball Materials, see Table E1.

Table E2.2 Number of balls per pound

NOM DIA Inches	MATERIAL DENSITY IN POUNDS PER CUBIC INCH												
	0.101	0.274	0.277	0.279	0.283	0.284	0.286	0.288	0.301	0.304	0.306	0.319	0.540
1/32	620,000	228,000	226,000	224,000	221,000	220,000	219,000	217,000	208,000	206,000	205,000	196,000	116,000
1/16	77,500	28,600	28,200	28,000	27,600	27,500	27,400	27,200	26,000	25,700	25,600	24,500	14,500
3/32	22,900	8,460	8,370	8,310	8,190	8,160	8,100	8,050	7,700	7,620	7,570	7,270	4,290
1/8	9,680	3,570	3,530	3,500	3,460	3,440	3,420	3,400	3,250	3,220	3,200	3,070	1,810
5/32	4,960	1,830	1,810	1,790	1,770	1,760	1,750	1,740	1,660	1,650	1,640	1,570	927
3/16	2,870	1,060	1,050	1,040	1,020	1,020	1,010	1,010	963	953	947	908	537
7/32	1,810	666	659	654	645	642	638	634	606	600	596	572	338
1/4	1,210	446	441	438	432	430	427	424	406	402	399	383	226
9/32	850	313	310	308	303	302	300	298	285	282	281	269	159
5/16	620	228	226	224	221	220	219	217	208	206	205	196	116
11/32	466	172	170	169	166	166	164	163	156	155	154	147	87
3/8	359	132	131	130	128	128	127	126	120	119	118	114	67
13/32	282	104	103	102	101	100	99.6	98.9	94.6	93.7	93.1	89.3	52.8
7/16	226	83.2	82.3	81.3	80.6	80.3	79.7	79.2	75.8	75.0	74.5	71.5	42.2
15/32	184	67.3	66.9	66.5	65.5	65.3	64.8	64.4	61.6	61.0	60.6	58.1	34.3
1/2	151	55.8	55.2	54.8	54.0	53.8	53.4	53.1	50.8	50.3	49.9	47.9	28.3
17/32	126	48.5	46.0	45.7	45.0	44.9	44.5	44.2	42.3	41.9	416.0	39.9	23.6
9/16	106	39.2	38.7	38.5	37.9	37.8	37.5	37.3	35.7	35.3	35.1	33.6	19.9
19/32	90.3	33.3	32.9	32.7	32.2	32.1	31.9	31.7	30.3	30.0	29.8	28.6	16.9
5/8	77.5	28.6	28.2	28.0	27.6	27.5	27.4	27.2	280	25.7	25.6	24.5	14.5
21/32	66.9	24.7	24.4	24.2	23.9	23.8	23.6	23.5	22.5	22.2	22.1	21.1	12.5
11/16	58.2	21.5	21.2	21.1	20.8	20.7	20.6	20.4	19.5	19.3	19.2	18.4	10.9
23/32	50.9	18.8	18.6	18.4	18.2	18.1	18.0	17.9	17.1	16.9	16.8	16.1	9.53
3/4	44.8	16.5	16.3	16.2	16.0	15.9	15.8	15.7	15.0	14.9	14.8	14.2	8.38
25/32	39.3	14.6	14.5	14.4	14.2	14.1	14.0	13.9	13.3	13.2	13.1	12.6	7.42
13/16	35.3	13.0	12.9	12.8	12.6	12.5	12.5	12.4	11.8	11.7	116.0	112	6.59
27/32	31.5	11.6	11.5	11.4	11.2	11.2	11.1	11.0	10.6	10.5	10.4	9.97	5.89
7/8	28.2	10.4	10.3	10.2	10.1	10.0	9.97	9.90	9.47	9.38	9.32	8.94	5.28
29/32	25.4	9.37	9.26	9.20	9.07	9.04	8.97	8.91	8.53	8.44	8.39	8.04	4.75
15/16	22.9	8.46	8.37	8.31	8.19	8.16	8.10	8.05	7.70	7.62	7.57	7.27	4.29
31/32	20.80	7.67	7.58	7.53	7.42	7.40	7.35	7.29	6.98	6.91	6.87	6.59	3.89
1	18.90	6.97	6.89	6.85	6.75	6.72	6.68	6.63	6.35	6.28	6.24	5.99	3.54
1-1/8	13.30	4.90	4.84	4.81	4.74	4.72	4.69	4.66	4.46	4.41	4.38	4.20	2.48
1-1/4	9.68	3.57	3.53	3.50	3.46	3.44	3.42	3.40	3.25	3.22	3.20	3.07	1.81
1-3/8	7.27	2.68	2.65	2.63	2.60	2.59	2.57	2.55	2.44	2.42	2.40	2.30	1.36
1-1/2	5.60	2.07	2.04	2.03	2.00	1.99	1.98	1.96	1.88	1.86	1.85	1.77	1.05
1 5/8	4.41	1.62	1.61	1.60	1.57	1.57	1.56	1.55	1.48	1.46	1.45	1.40	0.824
1-3/4	3.53	1.30	1.29	1.28	1.26	1.25	1.25	1.24	1.18	1.17	116.00	1.12	0.660
1-7/8	2.87	1.06	1.05	1.04	1.02	1.02	1.01	1.01	0.963	0.953	0.947	0.908	0.537
2	2.36	0.871	0.862	0.856	0.844	0.841	0.835	0.829	0.793	0.785	0.780	0.748	0.442
2-1/8	1.97	0.726	0.719	0.713	0.703	0.701	0.696	0.691	0.661	0.655	0.650	0.624	0.369
2-1/4	1.66	0.612	0.605	0.601	0.592	0.590	0.586	0.582	0.557	0.552	0.548	0.526	0.311
2-3/8	1.41	0.520	0.515	0.511	0.504	0.502	0.498	0.495	0.474	0.469	0.466	0.447	0.264
2-11/2	1.21	0.446	0.441	0.438	0.432	0.430	0.427	0.424	0.406	0.402	0.399	0.383	0.226
2-5/8	1.05	0.385	0.381	0.378	0.373	0.372	0.369	0.367	0.351	0.347	0.345	0.331	0.196
2-3/4	0.909	0.335	0.332	0.329	0.325	0.323	0.321	0.319	0.305	0.302	0.300	0.288	0.170
2-7/8	0.796	0.293	0.290	0.288	0.284	0.283	0.281	0.279	0.267	0.264	0.263	0.252	0.149
3	0.700	0.258	0.255	0.254	0.250	0.249	0.247	0.246	0.235	0.233	0.231	0.222	0.131
3-1/8	0.620	0.228	0.226	0.224	0.221	0.220	0.219	0.217	0.208	0.206	0.205	0.196	0.116
3-1/4	0.551	0.203	0.201	0.199	0.197	0.196	0.195	0.193	0.185	0.183	0.182	0.174	0.103
3-3/8	0.492	0.181	0.179	0.178	0.176	0.175	0.174	0.173	0.165	0.163	0.162	0.156	0.092
3-1/2	0.441	0.163	0.161	0.160	0.157	0.157	0.156	0.155	0.148	0.147	0.146	0.140	0.082
3-5/8	0.397	0.146	0.145	0.144	0.142	0.141	0.140	0.139	0.133	0.132	0.131	0.126	0.074
3 3/4	0.359	0.132	0.131	0.130	0.128	0.128	0.127	0.126	0.120	0.119	0.118	0.114	0.067
3-7/8	0.325	0.120	0.118	0.118	0.116	0.116	0.115	0.114	0.109	0.108	0.107	0.103	0.061
4	0.295	0.109	0.108	0.107	0.105	0.105	0.104	0.104	0.099	0.098	0.097	0.093	0.055
4-1/8	0.269	0.099	0.098	0.097	0.096	0.096	0.095	0.094	0.090	0.089	0.089	0.085	0.050
4-1/4	0.246	0.091	0.090	0.089	0.088	0.088	0.087	0.086	0.083	0.082	0.081	0.078	0.046
4-3/8	0.226	0.083	0.082	0.082	0.081	0.080	0.080	0.079	0.076	0.075	0.074	0.071	0.042
4-1/2	0.208	0.076	0.076	0.075	0.074	0.074	0.073	0.073	0.070	0.069	0.068	0.066	0.039

For Density of Ball Materials, see Table E1.

Table E3.1 -Weight of balls, kilograms per thousand balls

NOM DIA mm	MATERIAL DENSITY IN GRAMS PER CUBIC CENTIMETER												
	2.796	7.584	7.667	7.723	7.833	7.861	7.916	7.972	8.332	8.415	8.470	8.830	14.947
0.3	0.00004	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00011	0.00012	0.00012	0.00012	0.00012	0.00021
0.4	0.00009	0.00025	0.00026	0.00026	0.00026	0.00026	0.00027	0.00027	0.00028	0.00028	0.00028	0.00030	0.00050
0.5	0.00018	0.00050	0.00050	0.00051	0.00051	0.00051	0.00052	0.00052	0.00055	0.00055	0.00055	0.00058	0.00098
0.7	0.00050	0.00136	0.00138	0.00139	0.00141	0.00141	0.00142	0.00143	0.00150	0.00151	0.00152	0.00159	0.00268
0.8	0.00075	0.00203	0.00206	0.00207	0.00211	0.00211	0.00212	0.00214	0.00223	0.00226	0.00227	0.00237	0.00401
1.0	0.00146	0.00397	0.00401	0.00404	0.00412	0.00412	0.00415	0.00417	0.00436	0.00441	0.00443	0.00462	0.00783
1.2	0.0025	0.0069	0.0069	0.0070	0.0071	0.0071	0.0072	0.0072	0.0075	0.0076	0.0077	0.0080	0.0135
1.5	0.0049	0.0134	0.0135	0.0136	0.0139	0.0139	0.0140	0.0141	0.0147	0.0149	0.0150	0.0156	0.0264
2.0	0.0117	0.0318	0.0321	0.0323	0.0329	0.0329	0.0332	0.0334	0.0349	0.0352	0.0355	0.0370	0.0626
2.5	0.023	0.062	0.063	0.063	0.064	0.065	0.065	0.065	0.068	0.069	0.069	0.072	0.122
3.0	0.040	0.107	0.108	0.109	0.111	0.111	0.112	0.113	0.118	0.119	0.120	0.125	0.211
3.5	0.063	0.170	0.172	0.173	0.176	0.176	0.178	0.179	0.187	0.189	0.190	0.198	0.336
4.0	0.094	0.254	0.257	0.259	0.263	0.263	0.265	0.267	0.279	0.282	0.284	0.296	0.501
4.5	0.133	0.362	0.366	0.368	0.375	0.375	0.378	0.380	0.398	0.401	0.404	0.421	0.713
5.0	0.183	0.496	0.502	0.505	0.515	0.515	0.518	0.522	0.545	0.551	0.554	0.578	0.978
5.5	0.24	0.66	0.67	0.67	0.68	0.68	0.69	0.69	0.73	0.73	0.74	0.77	1.30
6.0	0.32	0.86	0.87	0.87	0.89	0.89	0.90	0.90	0.94	0.95	0.96	1.00	1.69
6.5	0.40	1.09	1.10	1.11	1.13	1.13	1.14	1.15	1.20	1.21	1.22	1.27	2.15
7.0	0.50	1.36	1.38	1.39	1.41	1.41	1.42	1.43	1.50	1.51	1.52	1.59	2.68
7.5	0.62	1.68	1.69	1.71	1.74	1.74	1.75	1.76	1.84	1.86	1.87	1.95	3.30
8.0	0.75	2.03	2.06	2.07	2.11	2.11	2.12	2.14	2.23	2.26	217	2.37	4.01
8.5	0.90	2.44	2.47	2.48	2.53	2.53	2.55	2.56	2.68	2.71	2.72	2.84	4.81
9.0	1.07	2.89	2.93	2.95	3.00	3.00	3.02	3.04	3.18	3.21	3.23	3.37	5.71
10.0	1.46	3.97	4.01	4.04	4.12	4.12	4.15	4.17	4.36	4.41	4.43	4.62	7.83
11.0	1.95	5.29	5.34	5.38	5.48	5.48	5.52	5.56	5.81	5.86	5.90	6.15	10.40
11.5	2.23	6.04	6.11	6.15	6.26	6.26	6.30	6.35	6.63	6.70	6.74	7.03	11.90
12.0	2.53	6.86	6.94	6.99	7.11	7.11	7.16	7.21	7.54	7.61	7.66	7.99	13.50
13.0	3.22	8.72	8.82	8.88	9.04	9.04	9.11	9.17	9.58	9.68	9.74	10.20	17.20
14.0	4.02	10.90	11.00	11.10	11.30	11.30	11.40	11.50	12.00	12.10	12.20	12.70	21.50
15.0	4.94	13.40	13.50	13.60	13.90	13.90	14.00	14.10	14.70	14.90	15.00	15.60	26.40
16.0	6.00	16.30	16.40	16.60	16.90	16.90	17.00	17.10	17.90	18.00	18.20	18.90	32.10
17.0	7.19	19.50	19.70	19.90	20.20	20.20	20.40	20.50	21.40	21.60	21.80	22.70	38.50
18.0	8.54	23.20	23.40	23.60	24.00	24.00	24.20	24.30	25.40	25.70	25.90	27.00	45.60
19.0	10.00	27.20	27.50	27.70	28.20	28.20	28.40	28.60	29.90	30.20	30.40	31.70	53.70
20.0	11.70	31.80	32.10	32.30	32.90	32.90	33.20	33.40	34.90	35.20	35.50	37.00	62.60
21.0	13.60	36.80	37.20	37.40	38.10	38.10	38.40	38.70	40.40	40.80	41.10	42.80	72.50
22.0	15.60	42.30	42.70	43.10	43.80	43.80	44.10	44.40	46.50	46.90	47.20	49.20	83.30
23.0	17.80	48.30	48.80	49.20	50.10	50.10	50.40	50.80	53.10	53.60	54.00	56.30	95.20
24.0	20.2	54.9	55.5	55.9	56.9	56.9	57.3	57.7	60.3	60.9	61.3	63.9	108.0
25.0	22.9	62.0	62.7	63.2	64.3	64.3	64.8	65.2	68.2	68.8	69.3	72.2	122.0
26.0	25.7	69.8	70.6	71.1	72.3	72.3	72.9	73.4	76.7	77.4	77.9	81.3	138.0
28.0	32.1	87.2	88.1	88.8	90.4	90.4	91.0	91.6	95.8	96.7	97.4	101.0	172.0
30.0	39.5	107.0	108.0	109.0	111.0	111.0	112.0	113.0	118.0	119.0	120.0	125.0	211.0
32.0	48.0	130.0	132.0	132.0	135.0	135.0	136.0	137.0	143.0	144.0	145.0	151.0	256.0
34.0	57.5	156.0	158.0	159.0	162.0	162.0	163.0	164.0	171.0	173.0	174.0	182.0	308.0
36.0	68.3	185.0	187.0	189.0	192.0	192.0	193.0	195.0	204.0	206.0	207.0	216.0	365.0
38.0	80.3	218.0	220.0	222.0	226.0	226.0	227.0	229.0	239.0	242.0	243.0	254.0	429.0
40.0	93.7	254.0	257.0	259.0	263.0	263.0	265.0	267.0	279.0	282.0	284.0	296.0	501.0
45.0	133.0	362.0	366.0	368.0	375.0	375.0	378.0	380.0	398.0	401.0	404.0	421.0	713.0
55.0	244	661	668	673	685	685	690	694	726	733	738	769	1300
60.0	316	858	867	873	889	889	895	902	942	952	958	999	1690
65.0	402	1090	1100	1110	1130	1130	1140	1150	1200	1210	1220	1270	2150

For Density of Ball Materials, see Table E1.

Table E3.2 - Weight of balls, pounds per thousand balls

NOM DIA Inches	MATERIAL DENSITY IN POUNDS PER CUBIC INCH												
	0.101	0.274	0.277	0.279	0.283	0.284	0.286	0.288	0.301	0.304	0.306	0.319	0.540
1/32	0.002	0.004	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.009
1/16	0.013	0.035	0.035	0.036	0.036	0.036	0.037	0.037	0.038	0.039	0.039	0.041	0.069
3/32	0.044	0.118	0.120	0.120	0.122	0.123	0.123	0.124	0.130	0.131	0.132	0.138	0.233
1/8	0.103	0.280	0.283	0.285	0.289	0.290	0.292	0.295	0.308	0.311	0.313	0.326	0.552
5/32	0.202	0.547	0.553	0.557	0.565	0.567	0.571	0.575	0.601	0.607	0.611	0.637	1.08
3/16	0.349	0.946	0.956	0.963	0.977	0.980	0.987	0.994	1.04	105.00	1.06	1.10	1.86
7/32	0.55	1.50	1.52	1.53	1.55	1.56	1.57	1.58	1.65	1.67	1.68	1.75	2.96
1/4	0.83	2.24	2.27	2.28	2.32	2.32	2.34	2.36	2.46	2.49	2.50	2.61	4.42
9/32	1.18	3.19	3.23	3.25	3.30	3.31	3.33	3.35	3.51	3.54	3.56	3.72	6.29
5/16	1.61	4.38	4.43	4.46	4.52	4.54	4.57	4.60	4.81	4.86	4.89	5.10	8.63
11/32	2.15	5.83	5.89	5.93	6.02	6.04	6.08	6.13	6.4	6.47	6.51	6.78	11.5
3/8	2.79	7.57	7.65	7.30	7.81	7.84	7.90	7.95	8.31	8.39	8.45	8.81	14.9
13/32	3.55	9.62	9.72	9.79	9.93	9.97	10.0	10.1	10.6	10.7	10.7	11.2	19.0
7/16	4.43	12.0	121.0	12.2	12.4	12.5	12.5	12.6	13.2	13.3	13.4	14.0	23.7
15/32	5.45	14.8	14.9	15.0	15.3	15.3	15.4	15.5	16.2	16.4	16.5	17.2	29.1
1/2	6.61	17.9	18.1	18.3	18.5	18.6	18.7	18.8	19.7	19.9	20.0	20.9	35.3
17/32	7.93	21.5	21.7	21.9	22.2	22.3	22.5	22.6	23.6	23.9	24.0	25.0	42.4
9/16	9.41	25.5	25.8	26.0	26.4	26.5	26.3	26.8	28.0	28.3	28.5	29.7	50.3
19/32	11.1	30.0	30.4	30.6	31.0	31.1	31.3	31.6	33.0	33.3	33.5	35.0	59.2
5/8	12.9	35.0	35.4	35.7	36.2	36.3	36.6	36.8	38.5	38.9	39.1	40.8	69.0
21/32	14.9	40.5	41.0	41.3	41.9	42.0	42.1	42.6	44.5	45.0	453.0	47.2	79.9
11/16	17.2	48.6	47.1	47.5	48.1	48.3	48.7	49.0	51.2	51.7	52.1	54.3	91.9
23/32	19.6	53.3	53.9	54.2	55.0	55.2	55.6	56.0	58.5	59.1	59.5	62.0	105
3/4	22.3	60.5	61.2	61.6	62.5	62.7	63.2	61.6	66.5	67.2	67.6	70.5	119
25/32	25.2	68.4	69.2	69.7	70.7	70.9	71.4	71.9	75.1	75.9	76A	79.6	135
13/16	28.4	77.0	77.8	78.4	79.5	79.8	80.3	80.9	84.5	85.4	85.9	89.6	152
27/32	31.8	86.2	87.1	87.7	89.0	89.3	89.9	90.6	94.7	95.6	96.2	100	170
7/8	35.4	96.1	97.2	97.9	99.3	99.6	100	191	1011	107	107	112	189
29/32	39.4	107	108	109	110	111	111	112	117	118	119	124	210
15/16	43.6	118	120	120	122	123	123	124	130	131	132	138	233
31/32	48.1	130	132	133	135	135	136	137	143	145	146	152	257
1	52.9	143	145	146	148	149	150	151	158	159	160	167	283
1-1/8	75.3	204	207	208	211	212	213	215	224	227	228	238	403
1-1/4	103	280	283	285	289	290	292	295	308	311	313	326	552
1-3/8	137	373	377	380	385	387	389	392	410	414	417	434	735
1-1/2	178	484	489	493	500	502	505	509	532	537	541	564	954
1 5/8	227	616	622	627	636	638	643	647	676	683	687	717	1,210
1-3/4	283	769	777	783	794	797	803	808	845	853	859	895	1,520
1-7/8	349	946	956	963	977	980	987	994	1,040	1,050	1,060	1,100	1,860
2	423	1,150	1,160	1,170	1,190	1,190	200	210	1,260	1,270	1,280	1,340	2,260
2-1/8	507	1,380	1,390	1,400	1,420	1,430	1,440	1,450	1,510	1,530	1,540	1,600	2,710
2-1/4	602	1,630	1,650	1,660	1,690	1,690	1,710	1,720	1,800	1,810	1,820	1,900	3,220
2-3/8	708	1,920	1,940	1,960	1,990	1,990	2,010	2,020	2,110	2,130	2,150	2,240	3,790
2-1/2	826	2,240	2,270	2,280	2,320	2,320	2,340	2,360	2,460	2,490	2,500	2,610	4,420
2-5/8	957	2,590	2,620	2,640	2,680	2,690	2,710	2,730	2,850	2,880	2,900	3,020	5,110
2-3/4	1,100	2,980	3,020	3,040	3,080	3,090	3,110	3,140	3,280	3,310	3,330	3,470	5,880
2-7/8	1,260	3,410	3,450	3,470	3,520	3,530	3,560	3,580	3,750	3,780	3,810	3,970	6,720
3	1,430	3,870	3,920	3,940	4,000	4,010	3,040	4,070	4,260	4,300	4,330	4,510	7,630
3-1/8	1,610	4,380	4,430	4,460	4,520	4,540	4,570	4,600	4,810	4,860	4,890	5,100	8,630
3-1/4	1,820	4,920	4,980	5,010	5,090	5,100	5,140	5,180	5,410	5,460	5,500	5,730	9,710
3-3/8	2,030	5,520	5,580	5,620	5,700	5,720	5,760	5,800	6,060	6,120	6,160	6,420	10,900
3-1/2	2,270	6,150	6,220	6,260	6,350	6,380	6,420	6,470	6,760	6,820	6,870	7,160	12,100
3-5/8	2,520	6,830	6,910	6,960	7,060	7,080	7,130	7,180	7,510	7,580	7,630	7,960	13,500
3 3/4	2,790	7,570	7,650	7,700	7,810	7,840	7,900	7,950	8,310	8,390	8,450	8,810	14,900
3-7/8	3,080	8,350	8,440	8,500	8,620	8,650	8,710	8,770	9,170	9,260	9,320	9,720	16,500
4	3,380	9,180	9,280	9,350	9,480	9,520	9,580	9,650	10,100	10,200	10,300	10,700	18,100
4-1/8	3,710	10,100	10,200	10,300	10,400	10,400	10,500	10,600	11,100	11,200	11,200	11,700	19,800
4-1/4	4,060	11,000	11,100	11,200	11,400	11,400	11,500	11,600	12,100	12,200	12,300	12,800	21,700
4-3/8	4,430	12,000	12,100	12,200	12,400	12,500	12,500	12,600	13,200	13,300	13,400	14,000	23,700
4-1/2	4,820	13,100	13,200	13,300	13,500	13,600	13,600	13,700	14,400	14,500	14,600	15,200	25,800

For Density of Ball Materials, see Table E1.