CHAPTER 22
UNTHREADED FASTENERS

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22.1 RIVETS

A *rivet* is a fastener that has a head and a shank and is made of a deformable material. It is used to join several parts by placing the shank into holes through the several parts and creating another head by upsetting or deforming the projecting shank.

During World War II, Rosie the Riveter was a popular cartoon character in the United States. No better image can illustrate the advantages of riveted joints. These are

1. Low cost
2. Fast automatic or repetitive assembly
3. Permanent joints
4. Usable for joints of unlike materials such as metals and plastics
5. Wide range of rivet shapes and materials
6. Large selection of riveting methods, tools, and machines

Riveted joints, however, are not as strong under tension loading as are bolted joints (see Chap. 23), and the joints may loosen under the action of vibratory tensile or shear forces acting on the members of the joint. Unlike with welded joints, special sealing methods must be used when riveted joints are to resist the leakage of gas or fluids.

22.1.1 Head Shapes

A group of typical rivet-head styles is shown in Figs. 22.1 and 22.2. Note that the button head, the oval head, and the truss head are similar. Of the three, the oval head has an intermediate thickness.

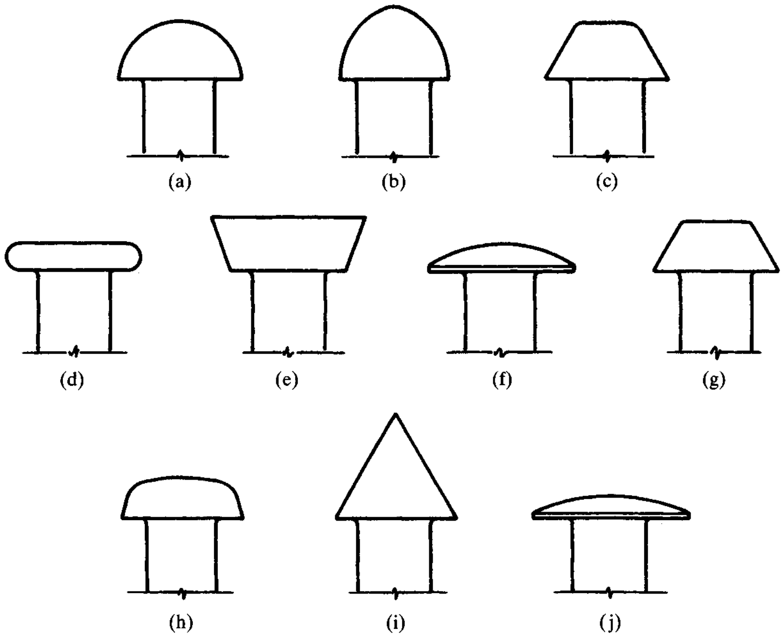


FIGURE 22.1 Standard rivet heads with flat bearing surfaces. (*a*) Button or round head; (*b*) high button or acorn head; (*c*) cone head; (*d*) flat head; (*e*) machine head; (*f*) oval head; (*g*) large pan head; (*h*) small pan head; (*i*) steeple head; (*j*) truss head, thinner than oval head.

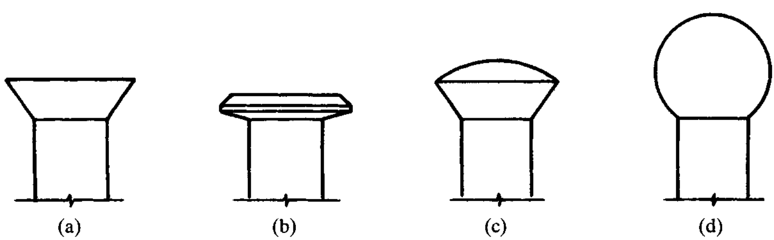


FIGURE 22.2 Various rivet heads. (*a*) Countersunk head; (*b*) countersunk head with chamfered top; (*c*) countersunk head with round top; (*d*) globe head.

A large rivet is one that has a shank diameter of ½ in or more; such rivets are mostly hot-driven. Head styles for these are button, high button, cone, countersunk, and pan. Smaller rivets are usually cold-driven. The countersunk head with chamfered flat top and the countersunk head with round top are normally used only on large rivets.

22.1.2 Rivet Types

The standard structural or machine rivet has a cylindrical shank and is either hot- or cold-driven.

A *boiler rivet* is simply a large rivet with a cone head.

A *cooper's rivet,* used for barrel-hoop joints, is a solid rivet with a head like that in Fig. 22.2*b* which has a shank end that is chamfered.

A *shoulder rivet* has a shoulder under the head.

A *tank rivet,* used for sheet-metal work, is a solid rivet with a button, countersunk, flat, or truss head.

A *tinner's rivet,* used for sheet-metal work, is a small solid rivet with a large flat head (Fig. 22.1*d*).

A *belt rivet,* shown in Fig. 22.3*a,* has a *riveting burr* and is used for leather or fabric joints.

A *compression* or *cutlery rivet,* shown in Fig. 22.3*b,* consists of a tubular rivet and a solid rivet. The hole and shank are sized to produce a drive fit when the joint is assembled.

A *split* or *bifurcated rivet,* shown in Fig. 22.3*c,* is a small rivet with an oval or countersunk head. The prongs cut their own holes when driven through softer metals or fibrous materials such as wood.

A *swell-neck rivet,* shown in Fig. 22.3*d,* is a large rivet which is used when a tight fit with the hole is desired.

A *tubular rivet,* shown in Fig. 22.3*e,* is a small rivet with a hole in the shank end. The rivet is cold-driven with a punchlike tool that expands or curls the shank end. *Semitubular rivets* are classified as those having hole depths less than 112 percent of the shank diameter.

A *blind rivet* is intended for use where only one side of the joint is within reach. The blind side is the side that is not accessible. However, blind rivets are also used where both sides of the joint can be accessed because of the simplicity of the assembly, the appearance of the completed joint, and the portability of the riveting tools. The rivets shown in Figs. 22.4 to 22.8 are typical of the varieties available.

22.1.3 Sizes and Materials

Large rivets are standardized in sizes from ½ to 1¾ in in ⅛-in increments. The nominal head dimensions may be calculated using the formulas in Table 22.1. The tolerances are found in Ref. [22.2]. The materials available are specified according to the following ASTM Specifications:

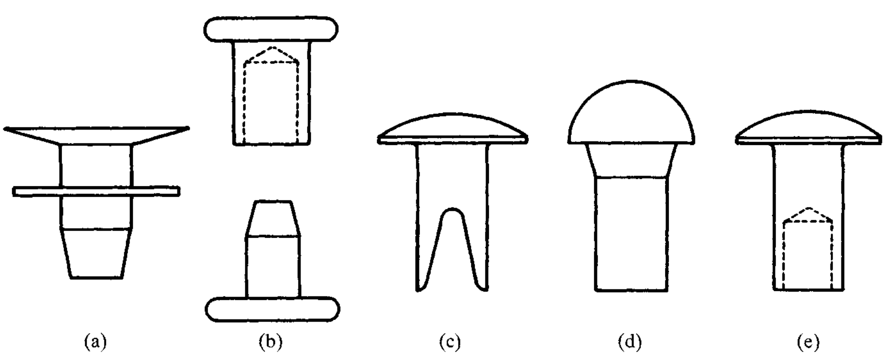


FIGURE 22.3 (*a*) Belt rivet; (*b*) compression rivet; (*c*) split rivet; (*d*) swell-neck rivet; (*e*) tubular rivet.

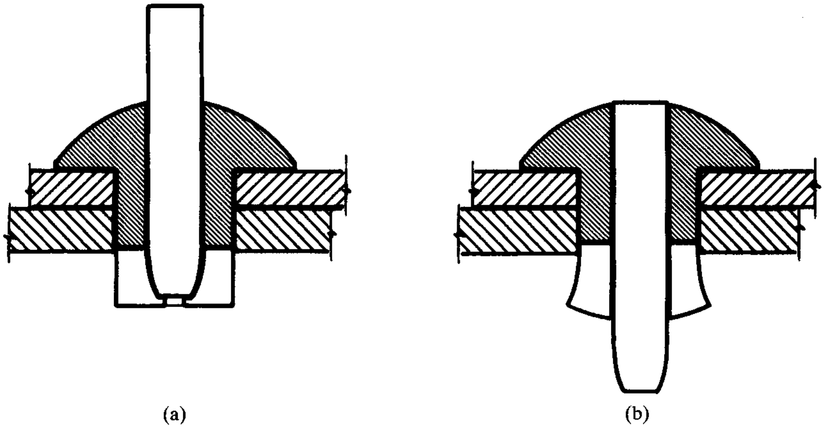


FIGURE 22.4 Drive-pin type of blind rivet. (*a*) Rivet assembled into parts; (*b*) ears at end of rivet expand outward when pin is driven.

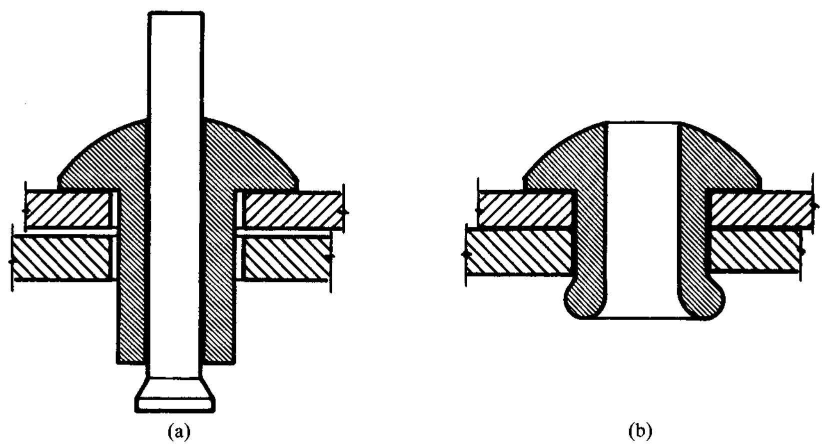


FIGURE 22.5 Pull-through-type blind riveting. (*a*) Before riveting; (*b*) after riveting.

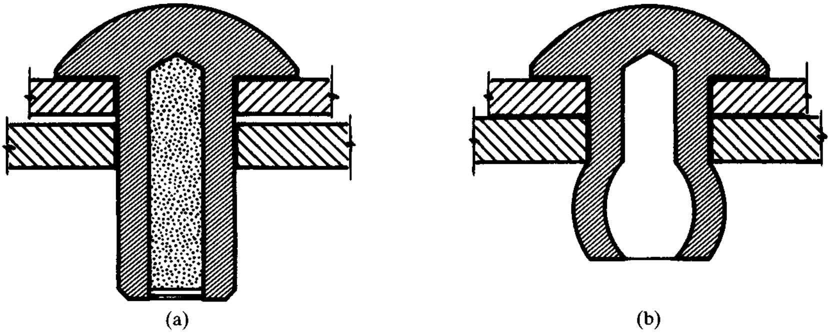


FIGURE 22.6 Explosive blind rivet. (*a*) Before explosion; (*b*) after; notice that the explosion clamps the joint.

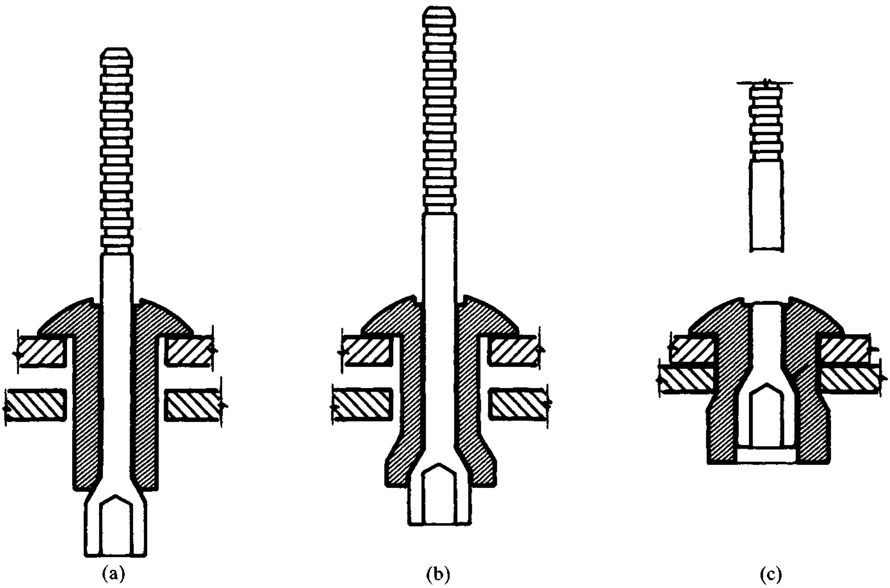


FIGURE 22.7 Self-plugging blind rivet. (*a*) Rivet inserted into prepared hole with power tool; (*b*) axial pull with power tool fills holes completely and clamps work pieces together; (*c*) stem separates flush with head and remaining section is locked in place. *(Avdel Corporation.)*

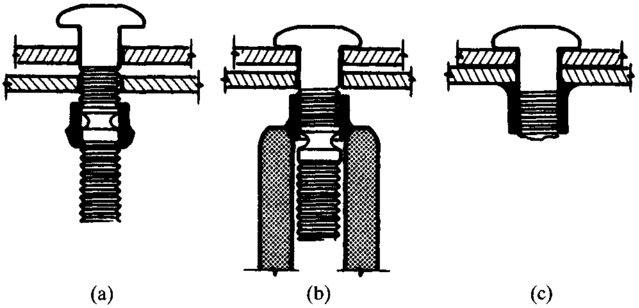


FIGURE 22.8 Lock-bolt or collar-type blind rivet. (*a*) Pin inserted through holes and collar placed over the pin tail; (*b*) nose tool pulls on the pin and reacts against the collar, clamping the work tightly; (*c*) installation finished by swaging the collar into the annular locking grooves and separating the pin at the breaker groove. *(Avdel Corporation.)*

A31 Boiler rivet steel.

A131 Rivet steel for ships.

A152 Wrought-iron rivets.

A502 Grade 1 carbon structural steel for general purposes. Grade 2 carbon-manganese steel for use with high-strength carbon and low-alloy steels.

TABLE 22.1 Head Dimensions for Large Rivets

Type of head	Diameter,† in		Height, in	Radius, in
	Major	Minor		
Button	1.750D	......	0.750D	0.885D
High button‡	1.500D + 0.031	......	0.750D + 0.125	0.750D + 0.281
Cone	1.750D	0.938D	0.875D	
Flat countersunk	1.810D	......	0.483D§	
Oval countersunk¶	1.810D	......	0.483D§	2.250D
Pan	1.600D	1.000D	0.700D	

†The nominal rivet diameter is D.
‡Side radius is 0.750D − 0.281.
§Varies, depending on shank and head diameters and the included angle.
¶Crown radius is 0.190D.
SOURCE: From Ref. [22.2].

Small solid rivets are standardized in sizes from 1⁄16 to 7⁄16 in in increments of 1⁄32 in. Note that some of these are not included in the table of preferred sizes (Table 48.4). Table 22.2 is a tabulation of standard head styles available and formulas for head dimensions. ASTM standard A31 Grade A or the SAE standard J430 Grade 0 are used for small steel rivets. But other materials, such as stainless steel, brass, or aluminum may also be specified.

Tinner's and cooper's rivets are sized according to the weight of 1000 rivets. A 5-lb rivet has a shank diameter of about 3⁄16 in. See Ref. [22.1] for sizes and head dimensions.

Belt rivets are standardized in gauge sizes from No. 14 to No. 4 using the Stubs iron-wire gauge (Table 48.17).

Tubular rivets are standardized in decimals of an inch; sizes corresponding to various head styles are listed in Tables 22.3 and 22.4. These are used with rivet caps, which are available in several styles and diameters for each rivet size. These rivets are manufactured from ductile wire using a cold-heading process. Thus any ductile material, such as steel, brass, copper, aluminum, etc., can be used. For standard tolerances, see Ref. [22.3].

Split rivet sizes are shown in Table 22.5. Split rivets are available in the same materials as tubular rivets and may be used with rivet caps too.

Some types of *blind rivets* are available in sizes from 3⁄32 to 3⁄8 in in diameter. The usual materials are carbon steel, stainless steel, brass, and aluminum. A variety of

TABLE 22.2 Head Dimensions for Small Solid Rivets

Head type	Diameter,† in	Height, in	Radius, in
Flat	2.000D	0.330D	
Flat countersunk	1.850D	0.425D	
Button	1.750D	0.750D	0.885D
Pan	1.720D	0.570D	3.430D‡
Truss	2.300D	0.330D	2.512D

TABLE 22.3 Sizes of Standard Semitubular Rivets†

Nominal size	Oval head		Truss head		Flat countersunk‡		Hole diameter§	Length increment
	Diameter	Thickness	Diameter	Thickness	Diameter	Thickness		
0.061	0.114	0.019	0.130	0.019	....	....	0.046	0.016
0.089	0.152	0.026	0.192	0.026	0.223	0.039	0.068	0.016
0.099	0.192	0.032	....	....	....	....	0.076	0.016
0.123	0.223	0.038	0.286	0.038	0.271	0.043	0.095	0.016
0.146	0.239	0.045	0.318	0.045	0.337	0.056	0.112	0.031
0.188	0.318	0.065	0.381	0.065	0.404	0.063	0.145	0.031
0.217	0.444	0.075	....	....	0.472	0.075	0.166	0.062
0.252	0.507	0.085	....	....	0.540	0.084	0.191	0.062
0.310	0.570	0.100	....	....	....	....	0.235	0.062

†Dimensions in inches; all values are maximums.
‡120-degree included angle; also available in 150-degree angle with chamfered top for friction materials.
§For Type T tapered hole; diameter is at end of rivet; also available as Type S straight hole.
SOURCE: From Ref. [22.3].

TABLE 22.4 Sizes of Standard Full Tubular Rivets†

Head shape	Nominal size	Head		Hole diameter
		Diameter	Thickness	
Oval	0.146	0.239	0.045	0.107
Truss	0.146	0.318	0.045	0.107
	0.188	0.381	0.065	0.141
Flat countersunk	0.146	0.317	0.050	0.107
	0.188	0.364	0.060	0.141

†Dimensions in inches; all values are maximum; maximum hole depth is to head.
‡Chamfered.
SOURCE: From Ref. [22.3].

TABLE 22.5 Sizes of Standard Split Rivets†

Nominal size	Oval head		Flat countersunk head	
	Diameter	Thickness	Diameter	Thickness
0.092	0.152	0.026		
0.125	0.223	0.035	0.223	0.036
0.152	0.318	0.045	0.317	0.053
0.152	....	....	0.380‡	0.062‡
0.190	0.349	0.055	0.443	0.061

†Dimensions in inches; all values are maximum.
‡Designates a *large flat countersunk head rivet.*
SOURCE: From Ref. [22.3].

head styles are available, but many of these are modifications of the countersunk head, the truss head, and the pan head. Head dimensions, lengths, and grips may be found in the manufacturer's catalogs.

22.2 PINS

When a joint is to be assembled in which the principal loading is shear, then the use of a pin should be considered because it may be the most cost-effective method. While a special pin can be designed and manufactured for any situation, the use of a standard pin will be cheaper.

Taper pins (Fig. 22.9*a*) are sized according to the diameter at the large end, as shown in Table 22.6. The diameter at the small end can be calculated from the equation

$$d = D - 0.208L$$

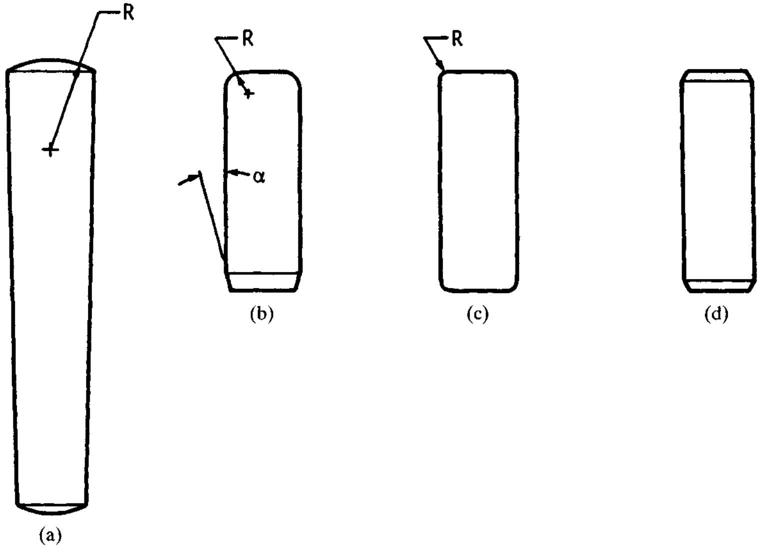


FIGURE 22.9 (*a*) Taper pin has crowned ends and a taper of 0.250 in/ft based on the diameter. (*b*) Hardened and ground machine dowel pin; the range of α is 4 to 16 degrees. (*c*) Hardened and ground production pin; corner radius is in the range 0.01 to 0.02 in. (*d*) Ground unhardened dowel pin or straight pin, both ends chamfered. Straight pins are also made with the corners broken.

where d = diameter at small end, in
D = diameter at large end, in
L = length, in

The constant in this equation is based on the taper. Taper pins can be assembled into drilled and taper-reamed holes or into holes which have been drilled by section. For the latter method, the first drill would be the smallest and would be drilled through. The next several drills would be successively larger and be drilled only part way (see Ref. [22.5]).

Dowel pins (Fig. 22.9*b, c,* and *d*) are listed in Tables 22.7 to 22.9 by dimensions and shear loads. They are case-hardened to a minimum case depth of 0.01 in and should have a single shear strength of 102 kpsi minimum. After hardening, the ductility should be such that they can be press-fitted into holes 0.0005 in smaller without cracking. See Chap. 19 for press fits.

Drive pins and studs are illustrated in Fig. 22.10 and tabulated in Tables 22.10 and 22.11. There are a large number of variations of these grooved drive pins. See Ref. [22.5] and manufacturers' catalogs. The standard grooved drive pin, as in Fig. 22.10*a* and *b,* has three equally spaced grooves. These pins are made from cold-drawn carbon-steel wire or rod, and the grooves are pressed or rolled into the stock. This expands the pin diameter and creates a force fit when assembled.

Spring pins are available in two forms. Figure 22.11*a* shows the slotted type of tubular spring pin. Another type, not shown, is a tubular pin made as a spiral by wrapping about 2¼ turns of sheet steel on a mandrel. This is called a *coiled spring pin.* Sizes and loads are listed in Tables 22.12 to 22.14.

TABLE 22.6 Dimensions of Standard Taper Pins (Inch Series)

Size no.	Diameter at large end				Lengths†
	Commercial		Precision		
	Max.	Min.	Max.	Min.	
7/0	0.0638	0.0618	0.0635	0.0625	$\frac{1}{4}$–1
6/0	0.0793	0.0773	0.0790	0.0780	$\frac{1}{4}$–$1\frac{1}{2}$
5/0	0.0953	0.0933	0.0950	0.0940	$\frac{1}{4}$–$1\frac{1}{2}$
4/0	0.1103	0.1083	0.1100	0.1090	$\frac{1}{4}$–2
3/0	0.1263	0.1243	0.1260	0.1250	$\frac{1}{4}$–2
2/0	0.1423	0.1403	0.1420	0.1410	$\frac{1}{2}$–$2\frac{1}{2}$
0	0.1573	0.1553	0.1570	0.1560	$\frac{1}{2}$–3
1	0.1733	0.1713	0.1730	0.1720	$\frac{3}{4}$–3
2	0.1943	0.1923	0.1940	0.1930	$\frac{3}{4}$–3
3	0.2203	0.2183	0.2200	0.2190	$\frac{3}{4}$–4
4	0.2513	0.2493	0.2510	0.2500	$\frac{3}{4}$–4
5	0.2903	0.2883	0.2900	0.2890	1–6
6	0.3423	0.3403	0.3420	0.3410	$1\frac{1}{4}$–6
7	0.4103	0.4083	0.4100	0.4090	$1\frac{1}{4}$–8
8	0.4933	0.4913	0.4930	0.4920	$1\frac{1}{4}$–8
9	0.5923	0.5903	0.5920	0.5910	$1\frac{1}{4}$–8
10	0.7073	0.7053	0.7070	0.7060	$1\frac{1}{2}$–8
11	0.8613	0.8593	.....	.....	2–8
12	1.0333	1.0313	.....	.....	2–9
13	1.2423	1.2403	.....	.....	3–11
14	1.5223	1.5203	.....	.....	3–13

†In preferred sizes but not in $\frac{1}{16}$-in increments; see Table 48.4 for list of preferred sizes in fractions of inches.

SOURCE: From Ref. [22.5].

Slotted tubular pins can be used inside one another to form a double pin, thus increasing the strength and fatigue resistance. When this is done, be sure the slots are not on the same radial line when assembled.

Clevis pins, shown in Fig. 22.11*b,* have standard sizes listed in Table 22.15. They are made of low-carbon steel and are available soft or case-hardened.

Cotter pins are listed in Table 22.16. These are available in the square-cut type, as in Fig. 22.11*c,* or as a hammer-lock type, in which the extended end is bent over the short end.

22.3 EYELETS AND GROMMETS

For some applications, eyelets are a trouble-free and economical fastener. They can be assembled very rapidly using special eyeleting and grommeting machines, which punch the holes, if necessary, and then set the eyelets. The eyelets are fed automatically from a hopper to the work point.

TABLE 22.7 Dimensions of Hardened Ground Machine Dowel Pins (Inch Series) (Fig. 22.9*b*)

Nominal size	Diameter				Shear load,† kip	Length‡
	Standard series		Oversize series			
	Max.	Min.	Max.	Min.		
$\frac{1}{16}$	0.0628	0.0626	0.0636	0.0634	0.80	$\frac{1}{16}$–$\frac{3}{4}$
$\frac{3}{32}$	0.0941	0.0939	0.0949	0.0947	1.80	$\frac{5}{16}$–1
$\frac{1}{8}$	0.1253	0.1251	0.1261	0.1259	3.20	$\frac{3}{8}$–2
$\frac{3}{16}$	0.1878	0.1876	0.1886	0.1884	7.20	$\frac{1}{2}$–2
$\frac{1}{4}$	0.2503	0.2501	0.2511	0.2509	12.8	$\frac{1}{2}$–$2\frac{1}{2}$
$\frac{5}{16}$	0.3128	0.3126	0.3136	0.3134	20.0	$\frac{1}{2}$–$2\frac{1}{2}$
$\frac{3}{8}$	0.3753	0.3751	0.3761	0.3759	28.7	$\frac{1}{2}$–3
$\frac{7}{16}$	0.4378	0.4376	0.4386	0.4384	39.1	$\frac{7}{8}$–3
$\frac{1}{2}$	0.5003	0.5001	0.5011	0.5009	51.0	$\frac{3}{4}$–4
$\frac{5}{8}$	0.6253	0.6251	0.6261	0.6259	79.8	$1\frac{1}{4}$–5
$\frac{3}{4}$	0.7503	0.7501	0.7511	0.7509	114.0	$1\frac{1}{2}$–6
$\frac{7}{8}$	0.8753	0.8751	0.8761	0.8759	156.0	2–6
1	1.0003	1.0001	1.0011	1.0009	204.0	2–6

†Minimum double shear load for carbon or alloy steel, manufacturer's responsibility to achieve.
‡Use Table 48.4 for preferred sizes in range given.
SOURCE: From Ref. [22.5].

TABLE 22.8 Dimensions of Hardened Ground Production Dowel Pins (Inch Series) (Fig. 22.9*c*)

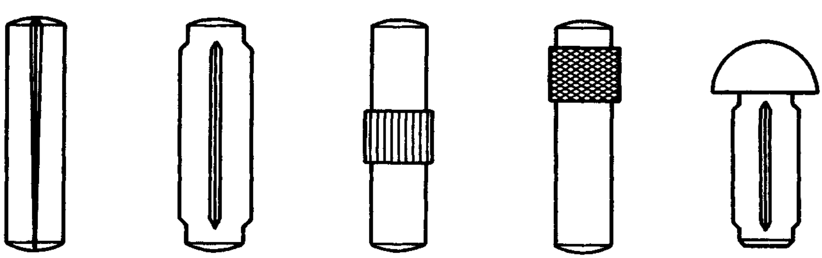
Nominal size	Diameter		Load,† kip	Length‡
	Max.	Min.		
$\frac{1}{16}$	0.0628	0.0626	0.79	$\frac{3}{16}$–1
$\frac{3}{32}$	0.0940	0.0938	1.40	$\frac{3}{16}$–2
$\frac{7}{64}$	0.1096	0.1094	1.90	$\frac{3}{16}$–2
$\frac{1}{8}$	0.1253	0.1251	2.60	$\frac{3}{16}$–2
$\frac{5}{32}$	0.1565	0.1563	4.10	$\frac{3}{16}$–2
$\frac{3}{16}$	0.1878	0.1876	5.90	$\frac{3}{16}$–2
$\frac{7}{32}$	0.2190	0.2188	7.60	$\frac{1}{4}$–2
$\frac{1}{4}$	0.2503	0.2501	10.0	$\frac{1}{4}$–$2\frac{1}{2}$
$\frac{5}{16}$	0.3128	0.3126	16.0	$\frac{5}{16}$–$2\frac{1}{2}$
$\frac{3}{8}$	0.3753	0.3751	23.0	$\frac{3}{8}$–3

†Minimum double shear load for carbon steel, manufacturer's responsibility to achieve.
‡See Table 48.4 for preferred sizes in range given.
SOURCE: From Ref. [22.5].

TABLE 22.9 Dimensions of Unhardened Dowel Pins and Straight Pins (Inch Series) (Fig. 22.9*d*)

Nominal size	Unhardened dowel pins					Straight pins	
	Diameter		Load,† kip			Diameter	
	Max.	Min.	Steel	Brass	Length‡	Max.	Min.
$\frac{1}{16}$	0.0600	0.0595	0.35	0.22	$\frac{1}{4}$–1	0.0625	0.0605
$\frac{3}{32}$	0.0912	0.0907	0.82	0.51	$\frac{1}{4}$–$1\frac{1}{2}$	0.0937	0.0917
$\frac{1}{8}$	0.1223	0.1218	1.49	0.93	$\frac{1}{4}$–2	0.1250	0.1230
$\frac{5}{32}$	0.1535	0.1530	2.35	1.47	$\frac{1}{4}$–2	0.1562	0.1542
$\frac{3}{16}$	0.1847	0.1842	3.41	2.13	$\frac{1}{4}$–2	0.1875	0.1855
$\frac{7}{32}$	0.2159	0.2154	4.66	2.91	$\frac{1}{4}$–2	0.2187	0.2167
$\frac{1}{4}$	0.2470	0.2465	6.12	3.81	$\frac{1}{4}$–$2\frac{1}{2}$	0.2500	0.2480
$\frac{5}{16}$	0.3094	0.3089	9.59	5.99	$\frac{5}{16}$–$2\frac{1}{2}$	0.3125	0.3105
$\frac{3}{8}$	0.3717	0.3712	13.85	8.65	$\frac{3}{8}$–$2\frac{1}{2}$	0.3750	0.3730
$\frac{7}{16}$	0.4341	0.4336	18.90	11.81	$\frac{7}{16}$–$2\frac{1}{2}$	0.4375	0.4355
$\frac{1}{2}$	0.4964	0.4959	24.72	15.45	$\frac{1}{2}$–3	0.5000	0.4980
$\frac{5}{8}$	0.6211	0.6206	38.71	24.19	$\frac{5}{8}$–4	0.6250	0.6230
$\frac{3}{4}$	0.7548	0.7453	55.84	34.90	$\frac{3}{4}$–4	0.7500	0.7480
$\frac{7}{8}$	0.8705	0.8700	76.09	47.55	$\frac{7}{8}$–4	0.8750	0.8730
1	0.9952	0.9947	99.46	62.16	1–4	1.0000	0.9980

†Minimum double shear load, manufacturer's responsibility to achieve.
‡See Table 48.4 for preferred sizes in range given.
SOURCE: From Ref. [22.5].



(a) (b) (c) (d) (e)

FIGURE 22.10 An assortment of drive pins. (*a*) Standard drive pin has three equally spaced grooves; (*b*) standard grooved drive pin with relief at each end; (*c*) (*d*) annular grooved and knurled drive pins; these may be obtained in a variety of configurations (*DRIV-LOK, Inc.*); (*e*) standard round head grooved stud.

TABLE 22.10 Dimensions of Grooved Drive Pins (Inch Series) (Fig. 22.10*a, b*)†

Basic size	Diameter		Expanded diameter‡	Length§
	Max.	Min.		
$\frac{1}{32}$	0.0312	0.0302	0.035	$\frac{1}{8}$–$\frac{1}{2}$
$\frac{3}{64}$	0.0469	0.0459	0.051	$\frac{1}{8}$–$\frac{5}{8}$
$\frac{1}{16}$	0.0625	0.0615	0.067	$\frac{1}{8}$–1
$\frac{5}{64}$	0.0781	0.0771	0.083	$\frac{1}{4}$–1
$\frac{3}{32}$	0.0938	0.0928	0.100	$\frac{1}{4}$–1$\frac{1}{4}$
$\frac{7}{64}$	0.1094	0.1074	0.115	$\frac{1}{4}$–1$\frac{1}{4}$
$\frac{1}{8}$	0.1250	0.1230	0.132	$\frac{1}{4}$–1$\frac{1}{2}$
$\frac{5}{32}$	0.1563	0.1543	0.163	$\frac{3}{8}$–2
$\frac{3}{16}$	0.1875	0.1855	0.196	$\frac{3}{8}$–2$\frac{1}{4}$
$\frac{7}{32}$	0.2188	0.2168	0.227	$\frac{1}{2}$–2$\frac{3}{4}$
$\frac{1}{4}$	0.2500	0.2480	0.260	$\frac{1}{2}$–3
$\frac{5}{16}$	0.3125	0.3105	0.326	$\frac{5}{8}$–3$\frac{1}{4}$
$\frac{3}{8}$	0.3750	0.3730	0.390	$\frac{3}{4}$–4$\frac{1}{4}$
$\frac{7}{16}$	0.4375	0.4355	0.454	$\frac{7}{8}$–4$\frac{1}{2}$
$\frac{1}{2}$	0.5000	0.4980	0.520	1–4$\frac{1}{2}$

†Reference [22.5] lists a total of seven different types of grooved drive pins.
‡Minimum; varies a few thousandths with length; ±0.002 in; not for Monel or stainless steel pins.
§In $\frac{1}{8}$-in increments only to 1 in.
SOURCE: From Ref [22.5].

TABLE 22.11 Dimensions of Round-Head Grooved Drive Studs (Inch Series) (Fig. 22.10*e*)

Size no.	Basic diameter	Head diameter max.	Head thickness max.	Expanded diameter†	Length
0	0.067	0.130	0.050	0.074	$\frac{1}{8}$–$\frac{1}{4}$
2	0.086	0.162	0.070	0.095	$\frac{1}{8}$–$\frac{1}{4}$
4	0.104	0.211	0.086	0.113	$\frac{3}{16}$–$\frac{5}{16}$
6	0.120	0.260	0.103	0.130	$\frac{1}{4}$–$\frac{3}{8}$
7	0.136	0.309	0.119	0.144	$\frac{5}{16}$–$\frac{1}{2}$
8	0.144	0.309	0.119	0.153	$\frac{3}{8}$–$\frac{5}{8}$
10	0.161	0.359	0.136	0.171	$\frac{3}{8}$–$\frac{5}{8}$
12	0.196	0.408	0.152	0.204	$\frac{1}{2}$–$\frac{3}{4}$
14	0.221	0.457	0.169	0.232	$\frac{1}{2}$–$\frac{3}{4}$
16	0.250	0.472	0.174	0.263	$\frac{1}{2}$ only

†Minimum; ±0.002 in.
SOURCE: From Ref. [22.5].

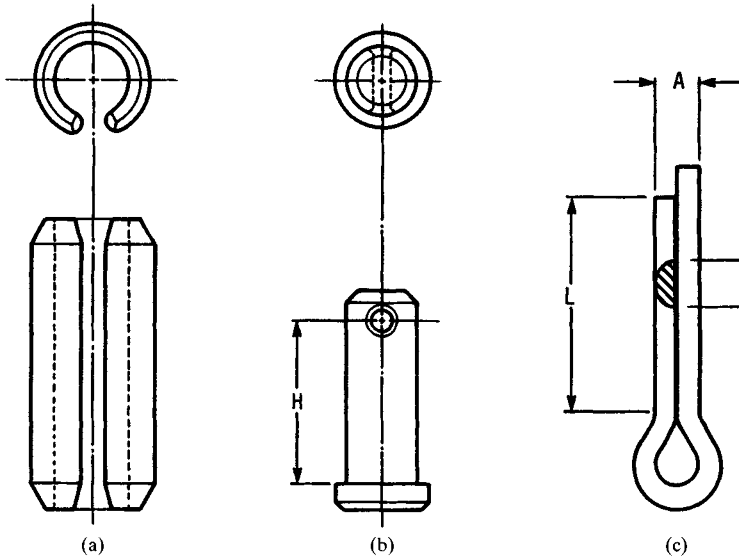


FIGURE 22.11 (*a*) Slotted spring pin; (*b*) clevis pin; (*c*) cotter pin.

TABLE 22.12 Dimensions and Safe Loads for Slotted Spring Pins (Inch Series) (Fig. 22.11*a*)

Size	Diameter		Hole size		Shear load,† kip		
	Max.	Min.	Max.	Min.	AISI 1070, AISI 1095, AISI 420	AISI 302	Beryllium copper
1/16	0.069	0.066	0.065	0.062	0.425	0.350	0.270
5/64	0.086	0.083	0.081	0.078	0.650	0.550	0.400
3/32	0.103	0.099	0.097	0.094	1.000	0.800	0.660
1/8	0.135	0.131	0.129	0.125	2.100	1.500	1.200
9/64	0.149	0.145	0.144	0.140	2.200	1.600	1.400
5/32	0.167	0.162	0.160	0.156	3.000	2.000	1.800
3/16	0.199	0.194	0.192	0.187	4.400	2.800	2.600
7/32	0.232	0.226	0.224	0.219	5.700	3.550	3.700
1/4	0.264	0.258	0.256	0.250	7.700	4.600	4.500
5/16	0.328	0.321	0.318	0.312	11.500	7.095	6.800
3/8	0.392	0.385	0.382	0.375	17.600	10.000	10.100
7/16	0.456	0.448	0.445	0.437	20.000	12.000	12.200
1/2	0.521	0.513	0.510	0.500	25.800	15.500	16.800
5/8	0.650	0.640	0.636	0.625	46.000‡	18.800	
3/4	0.780	0.769	0.764	0.750	66.000‡	23.200	

†Minimum double shear load, manufacturer's responsibility to achieve.
‡Sizes 5/8 in and larger are produced only in AISI 6150H.
SOURCE: From Ref. [22.5].

TABLE 22.13 Dimensions and Safe Loads for Coiled Spring Pins (Inch Series)

	Light duty				Standard duty				Heavy duty				Hole size	
	Diameter		Safe load,† kip		Diameter		Safe load,† kip		Diameter		Safe load,† kip			
Size	Max.	Min.	Mat. A‡	Mat. B§	Max.	Min.	Mat. A‡	Mat. B§	Max.	Min.	Mat. A‡	Mat. B§	Max.	Min.
$\frac{1}{32}$	....	....	....	....	0.035	0.033	0.075	0.060	....	....	....	....	0.032	0.031
$\frac{3}{64}$	....	....	....	....	0.052	0.049	0.170	0.140	....	....	....	....	0.048	0.046
$\frac{1}{16}$	0.073	0.067	....	0.135	0.072	0.067	0.300	0.250	0.070	0.066	0.450	0.350	0.065	0.061
$\frac{5}{64}$	0.089	0.083	....	0.225	0.088	0.083	0.475	0.400	0.086	0.082	0.700	0.550	0.081	0.077
$\frac{3}{32}$	0.106	0.099	0.375	0.300	0.105	0.099	0.700	0.550	0.103	0.099	1.000	0.800	0.097	0.093
$\frac{7}{64}$	0.121	0.114	0.525	0.425	0.120	0.114	0.950	0.750	0.118	0.113	1.400	1.250	0.112	0.108
$\frac{1}{8}$	0.139	0.131	0.675	0.550	0.138	0.131	1.250	1.000	0.136	0.130	2.100	1.700	0.129	0.124
$\frac{5}{32}$	0.172	0.163	1.100	0.875	0.171	0.163	1.925	1.550	0.168	0.161	3.000	2.400	0.160	0.155
$\frac{3}{16}$	0.207	0.196	1.500	1.200	0.205	0.196	2.800	2.250	0.202	0.194	4.400	3.500	0.192	0.185
$\frac{7}{32}$	0.240	0.228	2.100	1.700	0.238	0.228	3.800	3.000	0.235	0.226	5.700	4.600	0.224	0.217
$\frac{1}{4}$	0.273	0.260	2.700	2.200	0.271	0.260	5.000	4.000	0.268	0.258	7.700	6.200	0.256	0.247
$\frac{5}{16}$	0.339	0.324	4.440	3.500	0.337	0.324	7.700	6.200	0.334	0.322	11.500	9.200	0.319	0.308
$\frac{3}{8}$	0.405	0.388	6.000	5.000	0.403	0.388	11.200	9.000	0.400	0.386	17.600	14.000	0.383	0.370
$\frac{7}{16}$	0.471	0.452	8.400	6.700	0.469	0.452	15.200	13.000	0.466	0.450	22.500	18.000	0.446	0.431
$\frac{1}{2}$	0.537	0.516	11.000	8.800	0.535	0.516	20.000	16.000	0.532	0.514	30.000	24.000	0.510	0.493
$\frac{5}{8}$	....	....	....	....	0.661	0.642	31.000	25.000	0.658	0.640	46.000	37.000	0.635	0.618
$\frac{3}{4}$	....	....	....	....	0.787	0.768	45.000	36.000	0.784	0.766	66.000	53.000	0.760	0.743

†Minimum double shear load, manufacturer's responsibility to achieve.

‡Material A is AISI 1070, AISI 1095, or AISI 420; sizes $\frac{1}{32}$in and $\frac{3}{64}$in are available only in AISI 420; sizes $\frac{5}{8}$in and larger are available only in AISI 6150 steel.

§Material B is AISI 302.

SOURCE: From Ref. [22.5].

TABLE 22.14 Standard Lengths of Coiled and Slotted Spring Pins (Inch Series)†

Size	Length	Size	Length	Size	Length
$\frac{1}{32}$	$\frac{1}{8}$–$\frac{5}{8}$	$\frac{1}{8}$	$\frac{5}{16}$–2	$\frac{5}{16}$	$\frac{3}{4}$–4
$\frac{3}{64}$	$\frac{1}{8}$–$\frac{5}{8}$	$\frac{9}{64}$	$\frac{3}{8}$–2	$\frac{3}{8}$	$\frac{3}{4}$–4
$\frac{1}{16}$	$\frac{3}{16}$–1	$\frac{5}{32}$	$\frac{7}{16}$–$2\frac{1}{2}$	$\frac{7}{16}$	1–4
$\frac{5}{64}$	$\frac{3}{16}$–$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{1}{2}$–$2\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{4}$–4
$\frac{3}{32}$	$\frac{3}{16}$–$1\frac{1}{2}$	$\frac{7}{32}$	$\frac{1}{2}$–3	$\frac{5}{8}$	2–6
$\frac{7}{64}$	$\frac{1}{4}$–$1\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{2}$–$3\frac{1}{2}$		

†See Table 48.4 for list of preferred lengths.
SOURCE: From Ref. [22.5].

TABLE 22.15 Dimensions of Clevis Pins (Inch Series)

	Diameter		Maximum head			Distance H†			
Size	Max.	Min.	Diameter	Thickness	Hole Minimum	Max.	Min.	Length	Cotter pin size
$\frac{3}{16}$	0.186	0.181	0.32	0.07	0.073	0.504	0.484	0.58	$\frac{1}{16}$
$\frac{1}{4}$	0.248	0.243	0.38	0.10	0.073	0.692	0.672	0.77	$\frac{1}{16}$
$\frac{5}{16}$	0.311	0.306	0.44	0.10	0.104	0.832	0.812	0.94	$\frac{3}{32}$
$\frac{3}{8}$	0.373	0.368	0.51	0.13	0.104	0.958	0.938	1.06	$\frac{3}{32}$
$\frac{7}{16}$	0.436	0.431	0.57	0.16	0.104	1.082	1.062	1.19	$\frac{3}{32}$
$\frac{1}{2}$	0.496	0.491	0.63	0.16	0.136	1.223	1.203	1.36	$\frac{1}{8}$
$\frac{5}{8}$	0.621	0.616	0.82	0.21	0.136	1.473	1.453	1.61	$\frac{1}{8}$
$\frac{3}{4}$	0.746	0.741	0.94	0.26	0.167	1.739	1.719	1.91	$\frac{5}{32}$
$\frac{7}{8}$	0.871	0.866	1.04	0.32	0.167	1.989	1.969	2.16	$\frac{5}{32}$
1	0.996	0.991	1.19	0.35	0.167	2.239	2.219	2.41	$\frac{5}{32}$

†To hole center; see Fig. 22.11*b*.
SOURCE: From Ref. [22.4].

Figure 22.12 illustrates some of the more common eyelets and grommets. These are available in many other styles and in thousands of sizes. The usual materials are brass, copper, zinc, aluminum, steel, and nickel silver. Various finishing operations such as plating, anodizing, or lacquering can also be employed.

22.4 RETAINING RINGS

Shoulders are used on shafts and on the interior of bored parts to accurately position or retain assembled parts to prevent axial motion or play. It is often advantageous to use retaining rings as a substitute for these machined shoulders. Such rings can be used to axially position parts on shafts and in housing bores and often save a great deal in machining costs.

TABLE 22.16 Dimensions of Cotter Pins (Inch Series) (Fig. 22.11*c*)

Size	Shank diameter *A*		Wire width *B*		Hole size
	Max.	Min.	Max.	Min.	
$\frac{1}{32}$	0.032	0.028	0.032	0.022	0.047
$\frac{3}{64}$	0.048	0.044	0.048	0.035	0.062
$\frac{1}{16}$	0.060	0.056	0.060	0.044	0.078
$\frac{5}{64}$	0.076	0.072	0.076	0.057	0.094
$\frac{3}{32}$	0.090	0.086	0.090	0.069	0.109
$\frac{7}{64}$	0.104	0.100	0.104	0.080	0.125
$\frac{1}{8}$	0.120	0.116	0.120	0.093	0.141
$\frac{9}{64}$	0.134	0.130	0.134	0.104	0.156
$\frac{5}{32}$	0.150	0.146	0.150	0.116	0.172
$\frac{3}{16}$	0.176	0.172	0.176	0.137	0.203
$\frac{7}{32}$	0.207	0.202	0.207	0.161	0.234
$\frac{1}{4}$	0.225	0.220	0.225	0.176	0.266
$\frac{5}{16}$	0.280	0.275	0.280	0.220	0.312
$\frac{3}{8}$	0.335	0.329	0.335	0.263	0.375
$\frac{7}{16}$	0.406	0.400	0.406	0.320	0.438
$\frac{1}{2}$	0.473	0.467	0.473	0.373	0.500
$\frac{5}{8}$	0.598	0.590	0.598	0.472	0.625
$\frac{3}{4}$	0.723	0.715	0.723	0.572	0.750

SOURCE: From Ref. [22.4].

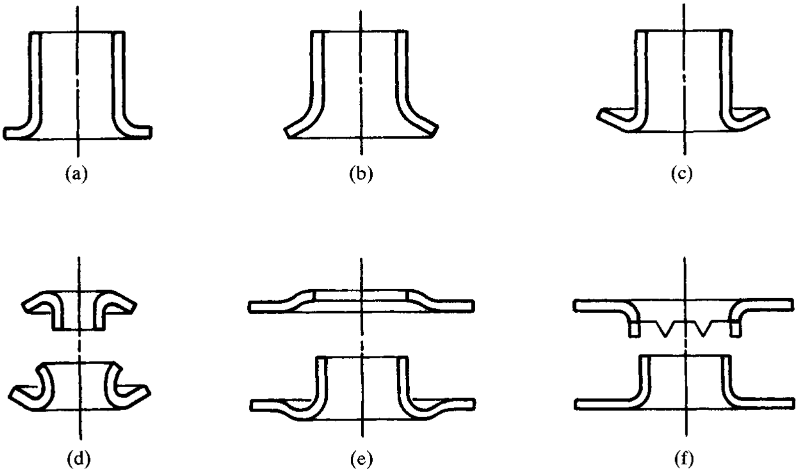


FIGURE 22.12 (*a*) Flat-flange eyelet; (*b*) funnel-flange eyelet; (*c*) rolled-flange eyelet; (*d*) telescoping eyelet with neck washer; (*e*) plain grommet; (*f*) toothed grommet.

Retaining rings may be as simple as a hardened spring wire bent into a C or U shape and fitted into a groove on a shaft or a housing. *Spiral-wound* and *stamped retaining rings* have been standardized (Refs. [22.7], [22.8], and [22.9]), and they are available in many shapes and sizes from various manufacturers.

22.4.1 Stamped Retaining Rings

Figure 22.13 shows a large variety of retaining rings. These are designated using the catalog numbers of a manufacturer, but can be changed to military standard numbers using Table 22.17.

The E rings shown in Fig. 22.13*a, b,* and *c* are intended to provide wide shoulders on small-diameter shafts. They are assembled by snapping them on in a radial direction. They are very satisfactory substitutes for cotter pins or the more expensive shaft shoulders or collars secured by set screws. Figure 22.14 shows typical mounting details for the rings in Fig. 22.13*a* and *b*. The ring in Fig. 22.13*c* is similar but is reinforced with tapered web sections for greater resistance to vibration and shock loads.

The C ring in Fig. 22.13*d* is also assembled radially, as will be shown in Fig. 22.17*a*. This ring is useful when axial access to the groove is difficult and for applications in which only a small shoulder is desired.

The internal rings in Fig. 22.13*e* and *f* are shown assembled in Fig. 22.15*a* and *b*. These are applied axially into grooved housings using specially designed pliers.

The external rings shown in Fig. 22.13*g* and *h* are shown assembled in Fig. 22.16. They are also assembled axially using pliers. Note how the bowed or dished ring in Fig. 22.16*b* can be used to take up end play or allow for temperature-induced dimensional changes.

The self-locking rings in Fig. 22.13*k* and *l* do not require grooves. They provide shoulders in soft materials, such as low-carbon steels or plastics, merely by pushing them axially into position. When a reverse force is applied, the prongs embed themselves into the mating material and resist removal.

The external self-locking ring in Figs. 22.13*m* and 22.17*b* may be used with or without a groove. This ring resists moderate thrust and provides an adjustable shoulder.

Materials for retaining rings are the spring steels, stainless steel, and beryllium copper. For dimensions and loads, see Refs. [22.7], [22.8], and [22.9] and the manufacturers' catalogs. They are available in both inch and metric sizes.

22.4.2 Spiral Wound Rings

Standard spiral-wound rings (Ref. [22.7]) have approximately two turns, although three-turn retaining rings are available. The rings are edge-wound from pretempered flat spring wire. The crimp or offset of the wire (see Fig. 22.18) produces a better seat, but rings are available without offset. Figure 22.18 also illustrates the machine methods of seating a ring into a housing or onto a shaft. Although difficult, manual seating is also possible.

Spiral-wound rings are sized by the inside diameter when they are to be used on a shaft and by the outside diameter when they are to be used in a housing. For sizes and thrust loads, see the manufacturers' catalogs. Usual materials are the plain carbon spring steels, stainless steel, nickel alloys, and beryllium copper.

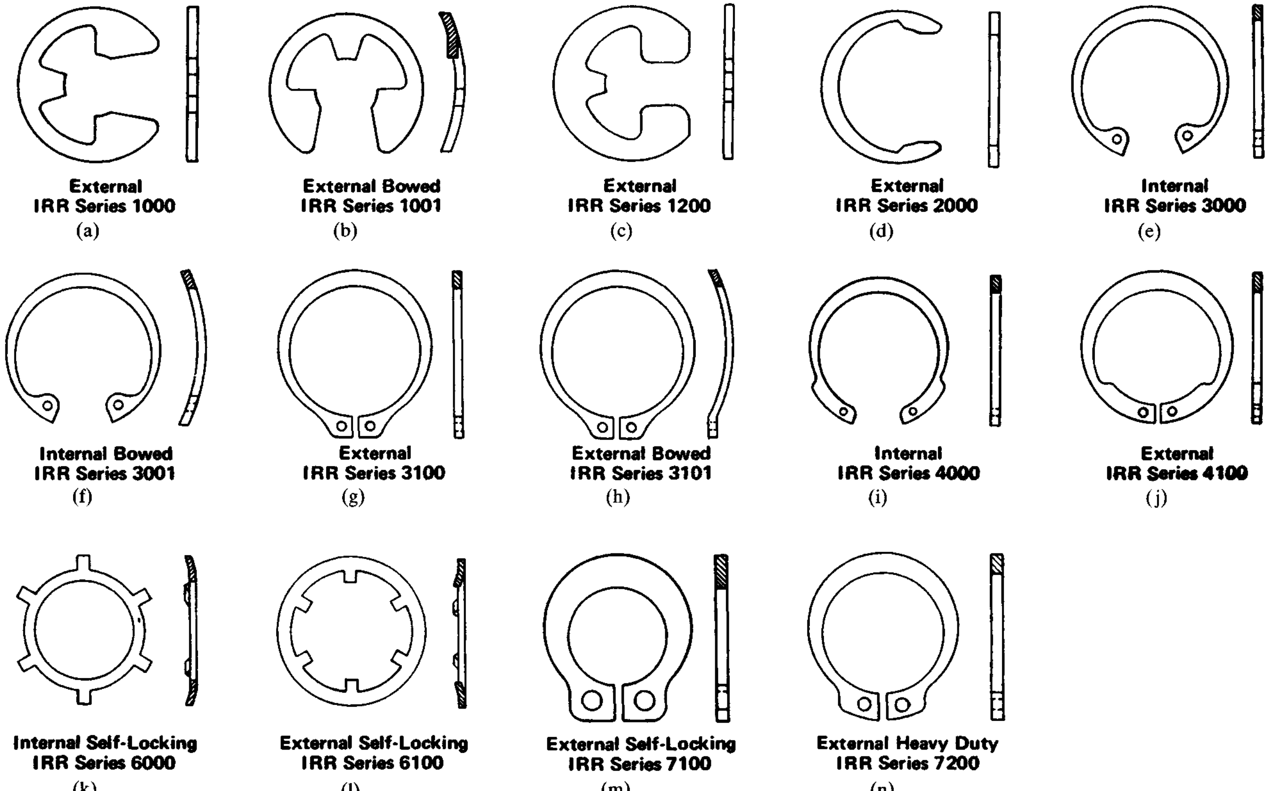
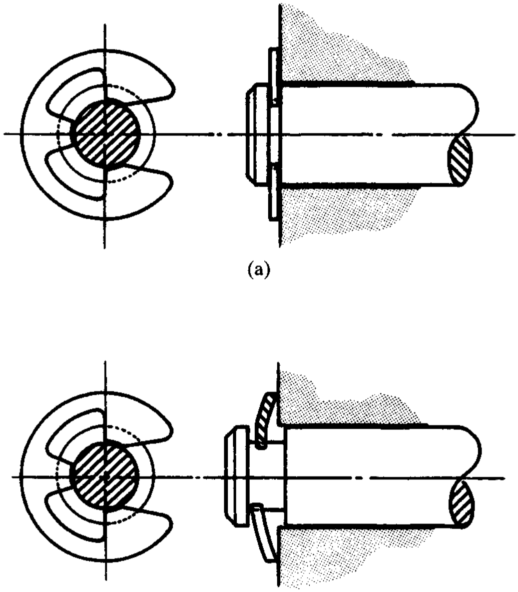


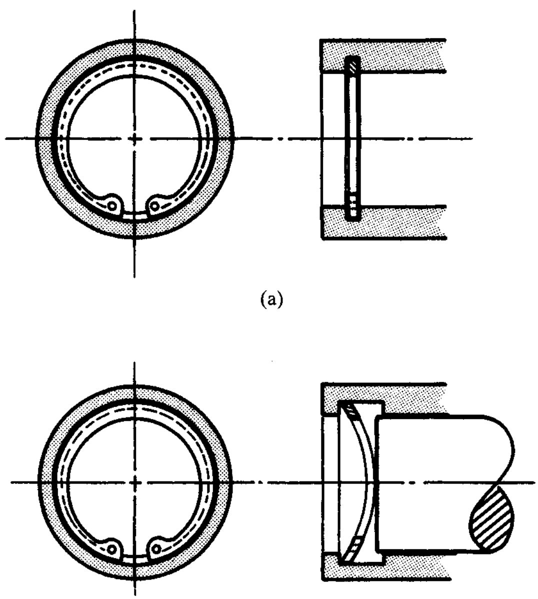
FIGURE 22.13 Retaining rings. The IRR numbers are catalog numbers. See Table 22.17 for conversion to military standard numbers. *(Industrial Retaining Ring Company.)*



(a)

(b)

FIGURE 22.14 Open-type E rings. (*a*) Flat; (*b*) bowed. *(Industrial Retaining Ring Company.)*



(a)

(b)

FIGURE 22.15 Internal rings. (*a*) Flat type (see Fig. 22.13*e* for shape before assembly); (*b*) bowed type (see Fig. 22.13*f* for shape before assembly).

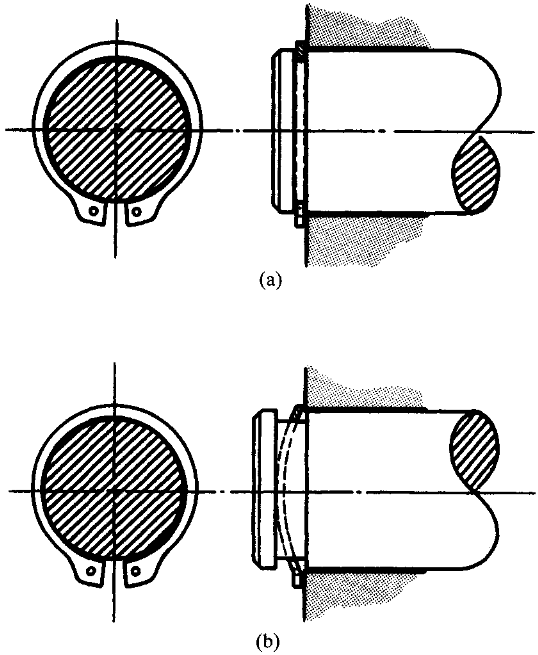


FIGURE 22.16 External rings. (*a*) Flat; (*b*) bowed. *(Industrial Retaining Ring Company.)*

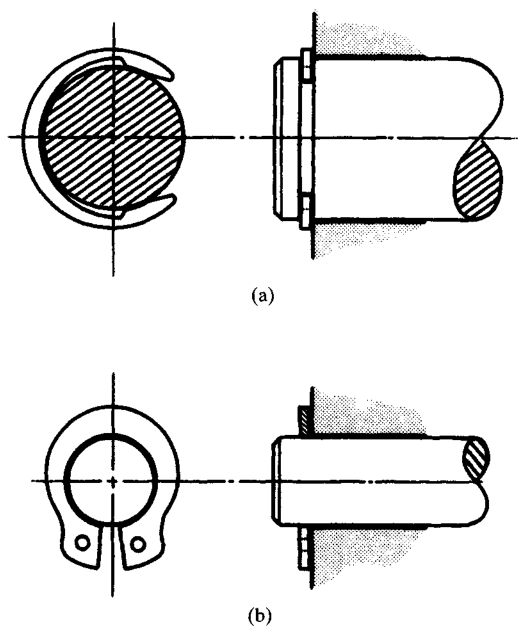


FIGURE 22.17 (*a*) External C-ring; (*b*) self-locking external ring. *(Industrial Retaining Ring Company.)*

TABLE 22.17 Conversion of IRR Catalog Numbers to Corresponding Military Standard Numbers of Retaining Rings

Government standard MS no.	IRR series no.	Government standard MS no.	IRR series no.
3215	1200	16628	3101
3217	7200	16629	3001
16624	3100	16632	2000
16625	3000	16633	1000
16626	4100	16634	1001
16627	4000	90707	7100

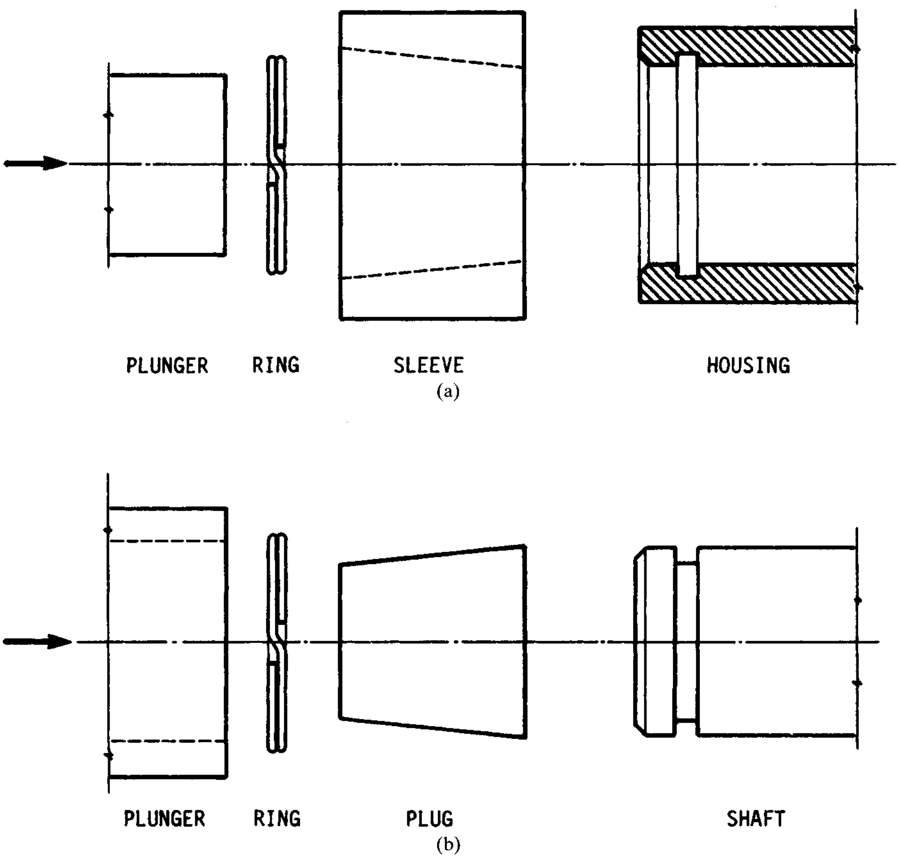


FIGURE 22.18 Spiral retaining rings. (*a*) Installation of ring into housing; (*b*) installation of ring onto shaft. *(Smalley Steel Ring Company.)*

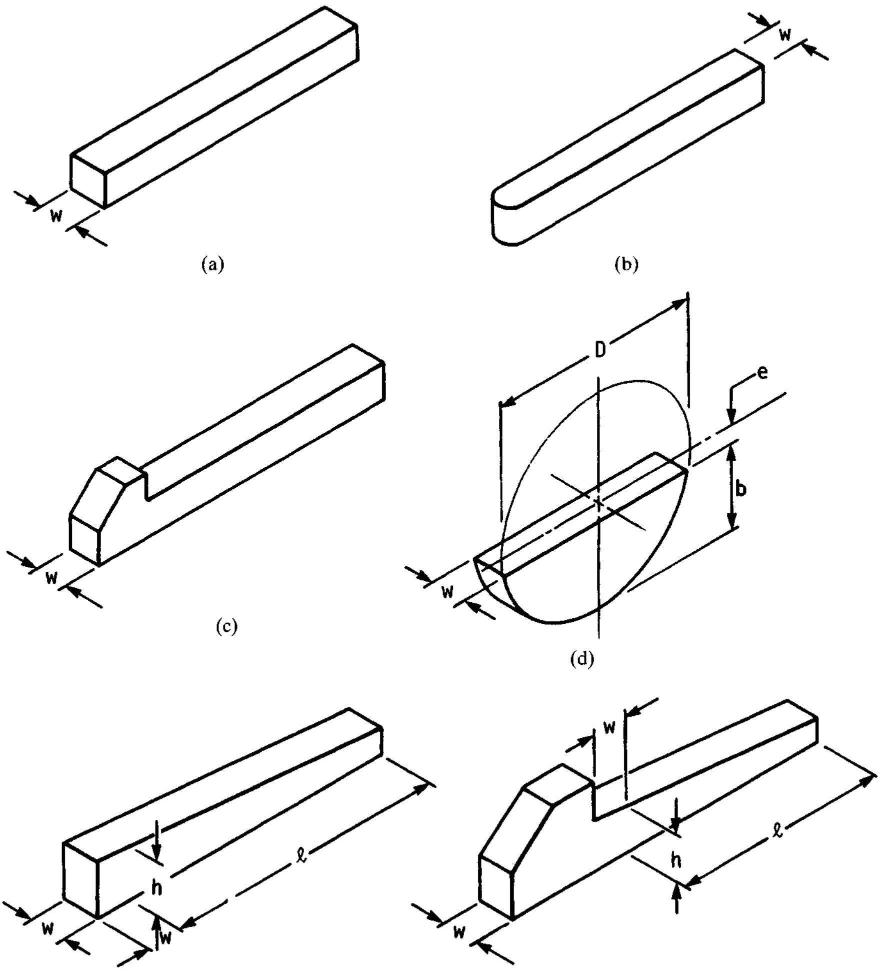


FIGURE 22.19 (*a*) Square or rectangular key. (*b*) Square or rectangular key with one end rounded; also available with both ends rounded. (*c*) Square or rectangular key with gib head. (*d*) Woodruff key; also available with flattened bottom. (*e*) Tapered rectangular key; ℓ = hub length, h = height; taper is ⅛ in for 12 in or 1 for 100 for metric sizes. (*f*) Tapered gib-head key; dimensions and taper same as in (*e*).

TABLE 22.18 Dimensions for Standard Square- and Rectangular-Key Applications†

Shaft diameter		Key size, $w \times h$	Keyway depth
Over	To (incl.)		
5/16	7/16	3/32 × 3/32	3/64
7/16	9/16	1/8 × 3/32	3/64
		1/8 × 1/8	1/16
9/16	7/8	3/16 × 1/8	1/16
		3/16 × 3/16	3/32
7/8	1 1/4	1/4 × 3/16	3/32
		1/4 × 1/4	1/8
1 1/4	1 3/8	5/16 × 1/4	1/8
		5/16 × 5/16	5/32
1 3/8	1 3/4	3/8 × 1/4	1/8
		3/8 × 3/8	3/16
1 3/4	2 1/4	1/2 × 3/8	3/16
		1/2 × 1/2	1/4
2 1/4	2 3/4	5/8 × 7/16	7/32
		5/8 × 5/8	5/16
2 3/4	3 1/4	3/4 × 1/2	1/4
		3/4 × 3/4	3/8
3 1/4	3 3/4	7/8 × 5/8	5/16
		7/8 × 7/8	7/16
3 3/4	4 1/2	1 × 3/4	3/8
		1 × 1	1/2
4 1/2	5 1/2	1 1/4 × 7/8	7/16
		1 1/4 × 1 1/4	5/8
5 1/2	6 1/2	1 1/2 × 1	1/2
		1 1/2 × 1 1/2	3/4

†Dimensions in inches
SOURCE: From Ref. [22.10].

TABLE 22.19 Dimensions for Standard Square- and Rectangular-Key Applications†

Shaft diameter		Key size, $w \times h$	Keyway depth
Over	To (incl.)		
6	8	2 × 2	1.2
8	10	3 × 3	1.8
10	12	4 × 4	2.5
12	17	5 × 5	3
17	22	6 × 6	3.5
22	30	8 × 7	4
30	38	10 × 8	5
38	44	12 × 8	5
44	50	14 × 9	5.5
50	58	16 × 10	6
58	65	18 × 11	7
65	75	20 × 12	7.5
75	85	22 × 14	9
85	95	25 × 14	9
95	110	28 × 16	10
110	130	32 × 18	11
130	150	36 × 20	12
150	170	40 × 22	13
170	200	45 × 25	15
200	230	50 × 28	17

†Dimensions in millimeters.

A *wave spring* is a one-turn edge-wound spring washer also made from flat spring wire. A thrust load tends to flatten the spring, and hence such springs can be used to take up end play or to allow for expansion. Several of these can be used together, either crest-to-crest or nested, depending on the requirements for thrust loads or axial motion.

22.5 KEYS

All standard plain, tapered, and Woodruff keys are illustrated in Fig. 22.19. These are usually made with edges broken, but they may be chamfered if fillets are used in the

TABLE 22.20 Dimensions for Woodruff-Key Applications (Fig. 22.19*d*)†

Key size, $w \times D$	Height‡ b	Offset e	Keyseat depth: Shaft	Keyseat depth: Hub
$\frac{1}{16} \times \frac{1}{4}$	0.109	$\frac{1}{64}$	0.0728	0.0372
$\times \frac{5}{16}$	0.140	$\frac{1}{64}$	0.1038	0.0372
$\times \frac{3}{8}$	0.172	$\frac{1}{64}$	0.1358	0.0372
$\frac{3}{32} \times \frac{5}{16}$	0.140	$\frac{1}{64}$	0.0882	0.0529
$\times \frac{3}{8}$	0.172	$\frac{1}{64}$	0.1202	0.0529
$\times \frac{1}{2}$	0.203	$\frac{3}{64}$	0.1511	0.0529
$\times \frac{5}{8}$	0.250	$\frac{1}{16}$	0.1981	0.0529
$\frac{1}{8} \times \frac{3}{8}$	0.172	$\frac{1}{64}$	0.1045	0.0685
$\times \frac{1}{2}$	0.203	$\frac{3}{64}$	0.1355	0.0685
$\times \frac{5}{8}$	0.250	$\frac{1}{16}$	0.1825	0.0685
$\times \frac{3}{4}$	0.313	$\frac{1}{16}$	0.2455	0.0685
$\frac{5}{32} \times \frac{5}{8}$	0.250	$\frac{1}{16}$	0.1669	0.0841
$\times \frac{3}{4}$	0.313	$\frac{1}{16}$	0.2299	0.0841
$\times \frac{7}{8}$	0.375	$\frac{1}{16}$	0.2919	0.0841
$\frac{3}{16} \times \frac{5}{8}$	0.250	$\frac{1}{16}$	0.1513	0.0997
$\times \frac{3}{4}$	0.313	$\frac{1}{16}$	0.2143	0.0997
$\times \frac{7}{8}$	0.375	$\frac{1}{16}$	0.2763	0.0997
$\times 1$	0.438	$\frac{1}{16}$	0.3393	0.0997
$\times 1\frac{1}{8}$	0.484	$\frac{5}{64}$	0.3853	0.0997
$\times 1\frac{1}{4}$	0.547	$\frac{5}{64}$	0.4483	0.0997
$\times 2\frac{1}{8}$	0.406	$\frac{21}{32}$	0.3073	0.0997
$\frac{7}{32} \times \frac{7}{8}$	0.375	$\frac{1}{16}$	0.2607	0.1153
$\times 1$	0.438	$\frac{1}{16}$	0.3237	0.1153
$\times 1\frac{1}{8}$	0.484	$\frac{5}{64}$	0.3697	0.1153
$\times 1\frac{1}{4}$	0.547	$\frac{5}{64}$	0.4327	0.1153
$\frac{1}{4} \times \frac{3}{4}$	0.313	$\frac{1}{16}$	0.1830	0.1310
$\times \frac{7}{8}$	0.375	$\frac{1}{16}$	0.2450	0.1310
$\times 1$	0.438	$\frac{1}{16}$	0.3080	0.1310
$\times 1\frac{1}{8}$	0.484	$\frac{5}{64}$	0.3540	0.1310
$\times 1\frac{1}{4}$	0.547	$\frac{5}{64}$	0.4170	0.1310
$\times 1\frac{3}{8}$	0.594	$\frac{3}{32}$	0.4640	0.1310
$\times 1\frac{1}{2}$	0.641	$\frac{7}{64}$	0.5110	0.1310
$\times 2\frac{1}{8}$	0.531	$\frac{17}{32}$	0.4010	0.1310
$\times 2\frac{3}{4}$	0.750	$\frac{5}{8}$	0.4640	0.1310
$\frac{5}{16} \times 1$	0.438	$\frac{1}{16}$	0.2768	0.1622
$\times 1\frac{1}{8}$	0.484	$\frac{5}{64}$	0.3228	0.1622
$\times 1\frac{1}{4}$	0.547	$\frac{5}{64}$	0.3858	0.1622
$\times 1\frac{3}{8}$	0.594	$\frac{3}{32}$	0.4328	0.1622
$\times 1\frac{1}{2}$	0.641	$\frac{7}{64}$	0.4798	0.1622
$\times 2\frac{1}{8}$	0.531	$\frac{17}{32}$	0.3698	0.1622
$\times 2\frac{3}{4}$	0.750	$\frac{5}{8}$	0.5888	0.1622
$\frac{3}{8} \times 1$	0.438	$\frac{1}{16}$	0.2455	0.1935
$\times 1\frac{1}{4}$	0.547	$\frac{5}{64}$	0.3545	0.1935
$\times 1\frac{3}{8}$	0.594	$\frac{3}{32}$	0.4015	0.1935
$\frac{3}{8} \times 1\frac{1}{2}$	0.641	$\frac{7}{64}$	0.4485	0.1935

TABLE 22.20 Dimensions for Woodruff-Key Applications (Fig. 22.19*d*)†
(Continued)

Key size, $w \times D$	Height‡ b	Offset e	Keyseat depth	
			Shaft	Hub
$\times 2\frac{1}{8}$	0.531	$\frac{17}{32}$	0.3385	0.1935
$\times 2\frac{3}{4}$	0.750	$\frac{5}{8}$	0.5575	0.1935
$\times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.7455	0.1935
$\frac{7}{16} \times 2\frac{3}{4}$	0.750	$\frac{5}{8}$	0.5263	0.2247
$\times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.7143	0.2247
$\frac{1}{2} \times 2\frac{3}{4}$	0.750	$\frac{5}{8}$	0.4950	0.2560
$\times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.6830	0.2560
$\frac{9}{16} \times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.6518	0.2872
$\frac{5}{8} \times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.6205	0.3185
$\frac{11}{16} \times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.5893	0.3497
$\frac{3}{4} \times 3\frac{1}{2}$	0.938	$\frac{13}{16}$	0.5580	0.3810

†All dimensions in inches. If catalog or key numbers are given, the last two digits correspond to the nominal diameter *D* in eighths of an inch. The preceding digits give the nominal width *w* in thirty-seconds of an inch. Thus key no. 1208 is a size $\frac{3}{8} \times 1$.

‡This is the maximum height for a full-radius key; this dimension will be slightly less for a flat-bottom key.

SOURCE: **From Ref. [22.11].**

keyseats. Standard sizes and keyseat dimensions needed for design are given in Tables 22.18 to 22.20.

22.6 WASHERS

Plain washers, shown in Fig. 22.20*a,* are flat and circular and are used on bolts and screws. They are applied under the nut, under the head, or both. Plain washers can also be made square or triangular and are sometimes beveled for use on an inclined surface.

Cylindrically curved or bent washers, shown in Fig. 22.20*b,* are useful in certain applications as a means of obtaining additional bolt tension in the joint.

Conical or Belleville washers, shown in Fig. 22.20*c* and *d,* are springs and are useful for heavy loads with small deflections and where a nonlinear force-deflection relation is desired. See Chap. 24 for more details.

Spring washers, shown in Fig. 22.20*e* and *f,* are hardened circular washers that are split and then bent out of a flat plane. They are sometimes called *lock washers,* although their principal purpose is to take up for relaxing bolt tension or looseness in the joint.

Wood-grip washers, shown in Fig. 22.21*a,* are useful on soft materials, such as wood. When the joint is tightened, the bent-over end penetrates and grips the mating material.

Horseshoe or C-washers are useful where it is desirable to remove the washer without unbolting the connection (see Fig. 22.21*b*).

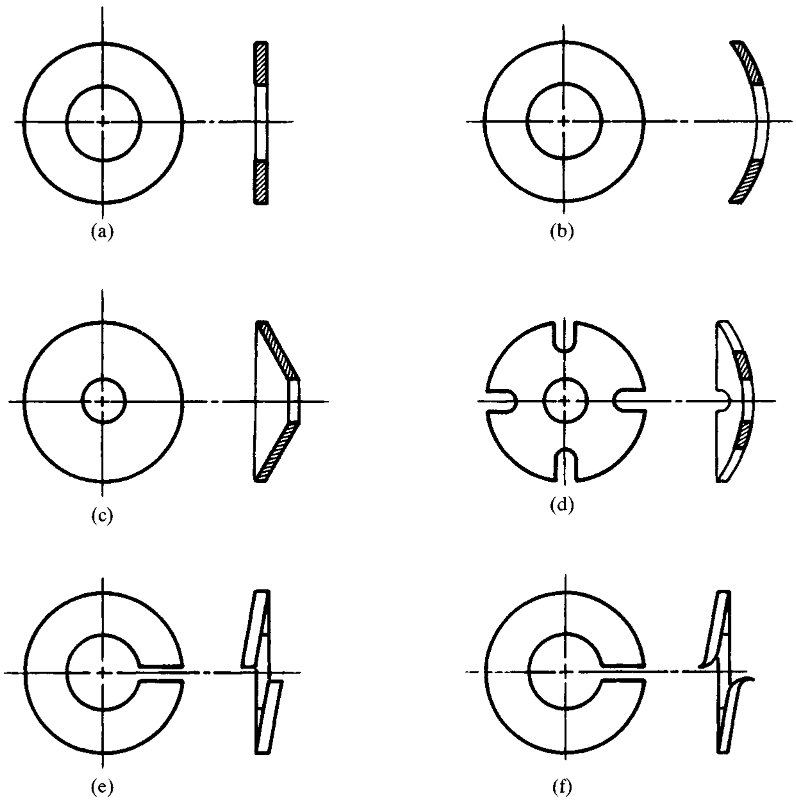


FIGURE 22.20 Washers. (*a*) Plain; (*b*) cylindrically curved; (*c*) conical or Belleville; (*d*) slotted; (*e*) spring; (*f*) spring-locking.

Lockplate or eared washers, shown in Fig. 22.21*c,* are used for locking purposes by bending some of the ears *up* against the flats of the nut or bolt head and others *down* over the edges of the joint members so as to prevent rotation of the nut or bolt head.

Cup washers, shown in Fig. 22.21*d,* are also available with a flange. When the depth of the cup is shallow, they are also called *back-up washers.*

Toothed lock washers, shown in Fig. 22.21*e,* have the teeth or prongs twisted so as to bite or penetrate the nut face as well as the adjoining part. These are hardened and made either with internal teeth or as internal-external toothed washers.

Countersunk washers, shown in Fig. 22.21*f,* serve the same purpose as plain washers when used with oval-head or countersunk-head screws.

Finish washers, shown in Fig. 22.22, are used under oval-head and flat-head screws to provide a more finished appearance and to increase the bearing surface between the fastener and the joint material.

Tables of washer sizes are not included here because of the large amount of space that would be required. Some manufacturers have as many as 60 000 stock dies, and so almost any size needed can be obtained. Washer materials include almost all the metals and many nonmetals as well.

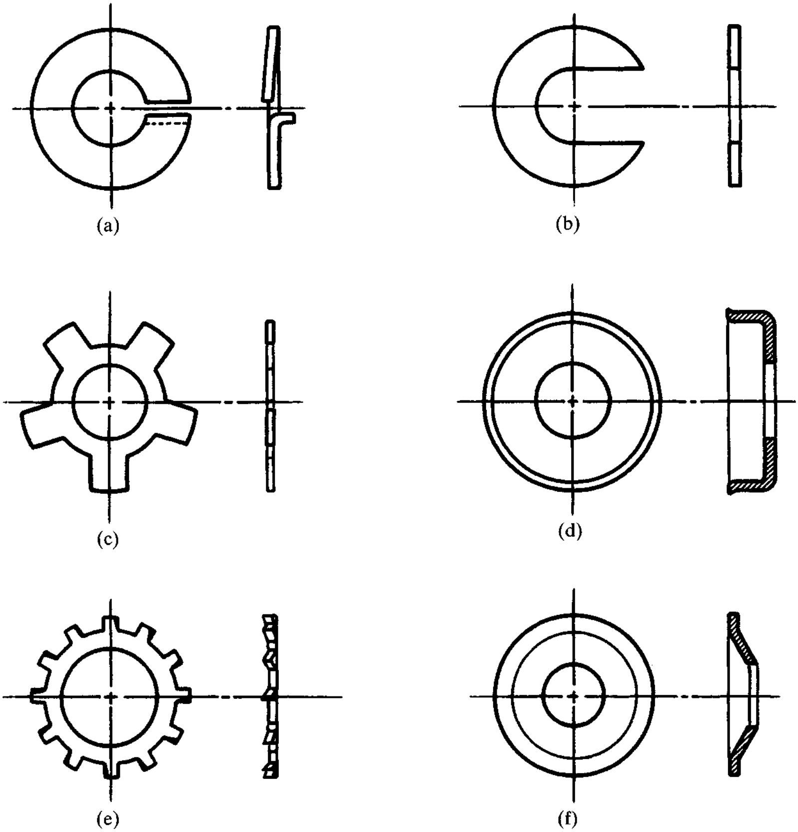


FIGURE 22.21 Washer. (*a*) Wood-grip; (*b*) C or horseshoe; (*c*) lockplate; (*d*) cup; (*e*) external-tooth locking; (*f*) countersunk.

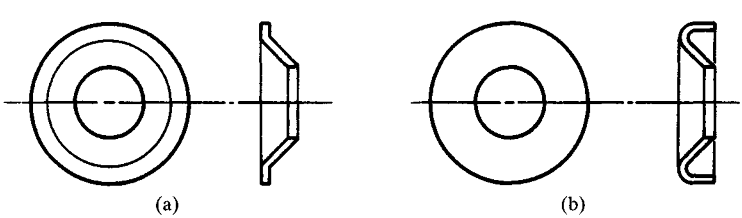


FIGURE 22.22 Finish washers. (*a*) Flush; (*b*) raised.

REFERENCES†

22.1 ANSI B18.1.1-1972 (R1977), "Small Solid Rivets."

22.2 ANSI B18.1.2-1972 (R1977), "Large Rivets."

22.3 ANSI B18.7-1972 (R1980), "General Purpose Semi-Tubular Rivets, Full Tubular Rivets, Split Rivets, and Rivet Caps."

22.4 ANSI B18.8.1-1972 (R1977), "Clevis Pins and Cotter Pins."

22.5 ANSI B18.8.2-1978, "Taper Pins, Dowel Pins, Straight Pins, Grooved Pins, and Spring Pins (Inch Series)."

22.6 ASA B18.12-1962 (R1981), "Glossary of Terms for Mechanical Fasteners."

22.7 ANSI B27.6-1972 (R1977), "General Purpose Uniform Cross Section Spiral Retaining Rings."

22.8 ANSI B27.7-1977, "General Purpose Tapered and Reduced Cross Section Retaining Rings (Metric)."

22.9 ANSI B27.8M-1978, "General Purpose Metric Tapered and Reduced Cross Section Retaining Rings."

22.10 ANSI B17.7-1967 (R1973), "Keys and Keyseats."

22.11 ANSI B17.2-1967 (R1978), "Woodruff Keys and Keyseats."

† References [22.1] to [22.5] and [22.7] to [22.11] are published by American Society of Mechanical Engineers; Ref. [22.6] is published by American Standards Association