used to produce acceptable welds. Welding processes and procedure are described in various publications.

Welding application requires the same basic knowledge of design as do the other types of assembly, but, in addition, requires a generous knowledge of welding principles and particularly the welding qualities of metal, its reaction to extremely high temperatures, and the ability to select and use only the best quality welding rods. This requirement applies equally to employer and employee, with the employer accepting all of the responsibility. Thus the employer should select his welding mechanics with good judgment, provide them with first-class equipment and tools, arrange for their training and use of acceptable workmanship standards, and at regular intervals subject their work to prescribed tests.

Rules for fusion welding of pipe joints, the qualification of welding operators, welding procedures, and testing are contained in the Standard Manual on Pipe Welding[3] and in publications of other groups.[1, 4, 5] In general, the wall thickness and chemical analysis of the pipe are the governing factors, not the working pressure. There are a number of safety codes which govern the installation of welded piping in many cities and states.

A complete line of manufactured steel welding fittings is now available, and a dimensional standard has been prepared under the procedure of the *American Standards Association*, (see Table 10) to unify heretofore divergent dimensions for the same type welding fittings produced by different manufacturers. Standard dimensions for steel butt-welding elbows, tees, caps, and lapped-joint stub ends are given in Table 10. Dimensions for eccentric and concentric reducers are not shown in Table 10, but are included in the standard.

Steel butt-welding fittings have beveled ends. For wall thicknesses less than 3/16 in., the bevel may be either 37½ deg. or cut square. For wall thicknesses of 3/16 in. to and including ¾ in. the bevel is 37½ deg. For walls larger than ¾ in. but not greater than 1¾ in., the bevel is U-shaped with a slope of 20 deg. above the 3/16 in. radius fillet. For walls greater than 1¾ in., the welding ends are prepared as agreed between the manufacturer and the purchaser.

Flange fittings may be welded from sizes ½ to 24 in. inclusive (see Table 12).

Socket-welding fittings also are commercially available. These fittings have a machined recess for inserting the pipe which is attached by a fillet weld between the pipe wall and socket end. Use of socket-welding fittings generally is restricted to nominal pipe sizes 3 in. and smaller in which range commercial fittings are available. This type of fitting has gained rapid acceptance owing to its ease of installation, low cost, and ability to make a pressure tight joint without weakening the pipe, as is the case with threading. Dimensions for socket-welding fittings, in accordance with *ASA* Standard B16.11-1946, are given in Table 13.

EXPANSION AND FLEXIBILITY

Changes in temperature cause a change in dimensions of any matter. The metals that are used for pipe have the same characteristics in that they expand with increasing temperature. If the metal is constrained so

that it cannot expand, then an internal compressive stress is set up in the material.

This stress can be calculated, just as any other stress, by using Hooke's Law.

$$F = \frac{eEA}{L} \tag{1}$$

where

F = Force of constraint, pounds.
e = Deformation, inches.
E = Modulus of elasticity, pounds per square inch.
A = Area of metal, square inches.
L = Length of metal, inches.

This equation is valuable in determining the internal stress of the pipe and also the constraining force on the anchors. This equation assumes that the stress is less than the yield strength of the metal. In other words, the metal will return to its original dimension when the temperature returns to its original level.

Table 19. Thermal Stresses due to Total Constraint

Temperature* Change, F Deg	Thermal Stresses, psi					
	Steel	Wrought Iron	Cast Iron	Brass or Bronze	Copper	Aluminum
20	3900	3800	1428	2760	2980	2700
40	7800	7600	2856	5520	5960	5400
60	11700	11400	4284	8280	8940	8190
80	15600	15200	5712	11040	11920	10800
100	19500	19000	7140	13800	14900	13500

* For temperatures between 32 and 400 F.

Materials such as cast iron are not ductile, hence the *yield strength* is approximately equal to the ultimate strength. These materials have excellent compressive strength but poor tensile strength. For this reason, it is difficult to bend these materials appreciably. Cast iron, for example, could be put in tension and, from Table 19, it is seen that for a temperature change of 100 deg., a compressive stress of 7140 psi would be developed. If the pipe were straight, this stress would be handled easily. If, however, the stress caused a bending moment, then fracture might occur.

The values of stress found in Table 19 were determined by using Equation 1 and substituting Equation 2 for e

$$e = aL\Delta t \tag{2}$$

where

a = coefficient of linear expansion, inches per inch.
Δt = temperature change, Fahrenheit degrees.

This gives Equation 3

$$F = aEA\Delta t \tag{3}$$

Values for a and E are given in Table 20 for various pipe materials, to