FABRICATION AND INSPECTION OF ALLOY STEEL PIPING

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IN the last ten years great strides have been made in the development of inert-gas shielded arc welding for the fabrication of steel alloy piping as used in steam power plants, refineries, the chemical industry and military and atomic energy installations. The world's expanding industries require ever more and better equipment in order to fill the demands of the people. There is hardly any industrial plant which does not use some welded alloy piping, may it be for corrosive chemicals, high-pressure steam, radioactive waste materials, etc.

The requirements of higher pressures, higher temperatures and higher corrosion resistance could only be met by newer and better steels. The metallurgist was placed in the position of having to produce tailor-made steels, and that is exactly what the steel manufacturers did.

Nowadays a designer can get the steel which exactly fits his requirements as to physical properties. The American Society for Testing Materials has tabulated and standardized these new steels, their qualities and possible uses and, in the case of welding, the welding electrodes to be used with these steels. Probably the largest consumers of these special steels for piping are the American petroleum industry and the American Government, both of which have their own specifications for their own special applications. Special piping for steam plants has to conform to the A.S.M.E. Boiler and Pressure Vessel Code.

Almost all welding of these special steels is done by the metallic arc process. Houston Pipe & Steel Inc. uses the following procedure for tungsten arc-metallic arc welding of stainless steel pipe, conforming to the A.S.M.E. Code.

Process — The welding shall be done by depositing the first pass (root) by the tungsten arc method shielded by inert gas and using an inert-gas back-up for prevention of oxidation and control of contour of the inside (root) bead (FIG. 1). The balance of the weld shall be made by the metal arc process when pipe wall thickness exceeds 0·250 in.

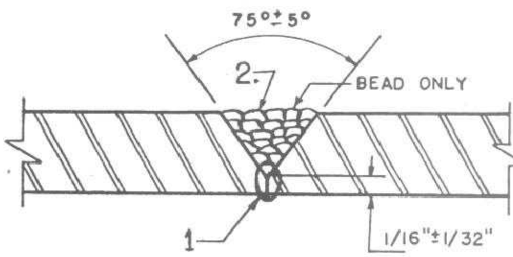


FIG. 1 — TUNGSTEN ARC INERT-GAS SHIELDED

1 — TUNGSTEN ARC INERT GAS SHIELDED
Electrode : $\frac{3}{32}$ in. diameter. Filler rod: None for flush, $\frac{3}{32}$ in. for inside reinforcement. Filler rod material: The filler material shall conform to the mechanical and chemical properties of the base material. Gas flow: 10 l./min.— pure argon. Cup size: No. 6 ceramic. Current: 80-100 amps., D.C. Voltage: 9-11 volts. Polarity: Straight.
2 — METAL ARC USE HPS SPEC. SS-2

Base Metal — The base materials shall be as shown in Section IX, A.S.M.E. Code 1952 — Table Q11-1-P-8.

Filler Metal — The filler metal shall conform to the mechanical and chemical properties as shown in Table Q11-3-P-8 and shall match the base material or be compatible.

Position — Welding shall be done in the horizontal and vertical positions.

Preparation of the Base Material — The edges of the parts to be joined shall be prepared by machining, flux injection, cutting, sawing or grinding and shall be cleaned of all foreign substances, oil or grease, and oxidation by the use of wire brushes, steel wool or grinding material that has only been used on stainless steel and/or by etching.

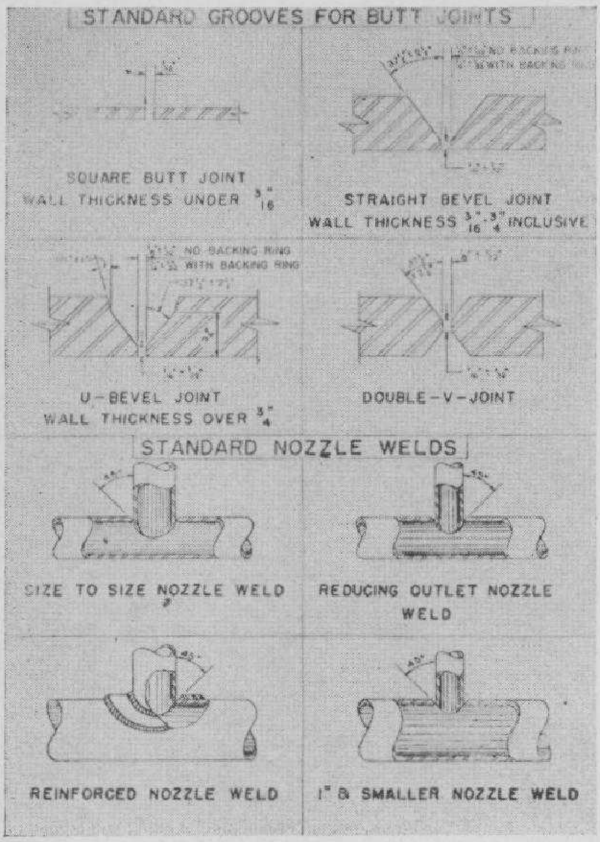


FIG. 2—WELDING TECHNIQUE—STANDARD GROOVES FOR BUTT JOINTS

Nature of the Electric Current — The current shall be D.C. straight polarity with the base material to be on the positive side for root pass, balance reverse polarity.

Welding Technique — The welding technique shall be as shown on Fig. 2.

Cleaning — All oxidation remaining on any bead of welding shall be removed before laying down the next successive bead of welding.

Defects — Any cracks or blow-holes that appear on the surface of any weld bead shall be removed by chipping or grinding, using tools that have only been used on stainless steel, before depositing the next successive bead of welding.

Peening — None.

Treatment of Underside of Groove — No backing rings shall be used, but full penetration shall be achieved to make the joint equivalent to a double-welded butt joint. An inert-gas back may be used to prevent oxidation and to control the contour of the inside of the root bead.

Preheating — None contemplated as no welding is to be done under an ambient temperature of 70°.

Heat Treatment — As agreed between the fabricator and the purchaser, no heat treatment contemplated on ELC or stabilized material.

This same company used practically the same procedure when welding chrome-molybdenum alloy piping, except for preheating and heat treatment, as follows:

Preheating — 400°-800°F. before welding is started and maintaining a minimum interpass temperature of 300°F. according to base material specification.

Heat Treatment — Stress-relieving shall be done after the weld has cooled to room temperature and according to the specification covering the base material, but in general 1350°-1375°F. for a period of 1 hr. per inch of wall thickness.

Mr. R. T. Pursell of the Stone & Webster Engineering Corporation, in an article on welding of pressure piping, introduces a novel preparation of the root for welding chrome-molybdenum pipe joints, as shown in Fig. 3.

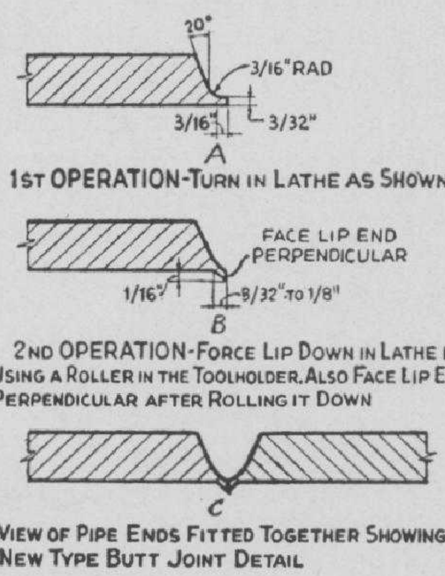
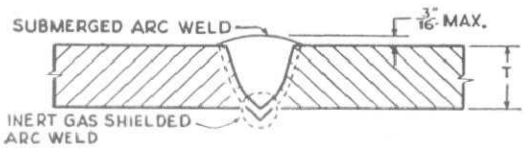


FIG. 3 — NOVEL MANNER OF PREPARING ROOT EDGES FOR CHROME-MOLYBDENUM PIPE

TABLE 1 — WELDING TECHNIQUE FOR CHROME-MOLYBDENUM PIPING

Type of Joint — Single U-Butt Joint



Inert-gas Shielded Arc Welding Technique

Beads	Filler rod	*Tungsten electrode	†Gas cap.	Welding gas, argon c.f.h.	Purging gas, argon c.f.h.	D.C. Str. pol. I	V
1	None	$\frac{3}{32}$	5 l.	15	5	120-140	10-14
2	$\frac{1}{8}$	$\frac{3}{32}$	5 l.	15	5	140-150	10-14

*Thoriated tungsten. †Metal cup, long neck.

Submerged Arc Welding Technique

T	Filler rod	Beads	D.C. — Rev. pol. amps.	volts.	Welding speed, i.p.m.—average
$\frac{1}{2}$	$\frac{3}{32}$	10	175-225	28-32	10-15
$\frac{5}{8}$	$\frac{3}{32}$	12	175-225	28-32	10-15
$\frac{3}{4}$	$\frac{3}{32}$	14	175-225	28-32	10-15
$\frac{7}{8}$	$\frac{3}{32}$	16	200-250	30-34	10-15
1	$\frac{3}{32}$	20	200-250	30-34	10-15
$1\frac{1}{8}$	$\frac{3}{32}$	25	200-250	30-34	10-15
$1\frac{1}{4}$	$\frac{3}{32}$	30	200-275	32-35	10-15
$1\frac{1}{2}$	$\frac{3}{32}$	32	200-275	32-35	10-15
$1\frac{5}{8}$	$\frac{3}{32}$	35	200-300	32-36	10-15
$1\frac{3}{4}$	$\frac{3}{32}$	40	200-300	32-36	8-15
2	$\frac{3}{32}$	50	200-300	32-36	8-15

NOTES: The number of beads required may vary slightly, those given in the table represent an average.

The welding amperage, voltage and speed will vary between the first two or three beads and the reinforcement beads in order to obtain desirable results.

It is quite evident that with this procedure one has all the advantages of a back-up ring without any of the undesirable properties. Table 1 gives some details of this procedure for making single U-butt joints on chrome-molybdenum piping. The field erection of the shop-fabricated sections is in most cases done by the same welding procedure. However, all welds are radiographically inspected after stress-relieving.

FIG. 4 — HEAVY WALL PIPE SECTIONS SHOWING EDGE PREPARATION

The radiographic inspection of these field welds is rather difficult due, not only to the location of the welds, but also to the extra heavy wall thicknesses encountered, as shown in Fig. 4.

Some of the main steam piping for the Electric Energy plant in Joppa, Illinois, had wall thicknesses up to 4 in. Various radiographic procedures have been used for this type of work. It was evident that X-ray machines could not be employed; radioactive isotopes of large millicurie concentration were needed and the following procedures were used (FIG. 5):

Method A placed the source in the centre of the weld through a hole drilled through one pipe wall.

Method B had the source inserted into a sponge rubber ball which was then drawn through the pipe until it was in the centre of the weld.

Method C placed the source right on the outside of the weld and took a radiograph of part of the opposite weld circumference.

Method D placed the source a distance of seven times the pipe-diameter away from the weld and slightly off the plane of the weld to give an eliptical image of the weldment.

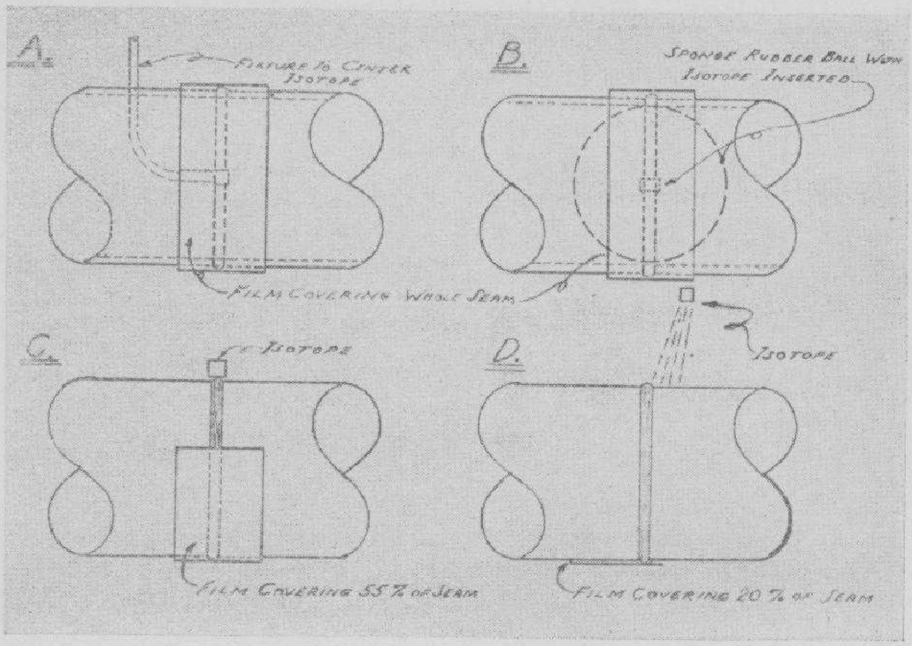


FIG. 5 — RADIOGRAPHIC PROCEDURES

With methods A and B, one exposure radiographed the whole seam. With method C, a maximum of 55 per cent of the weld could be radiographed with one exposure. The coverage with this procedure depends on the wall thickness and diameter of the pipe. With method D, an eliptical image of the weld was obtained giving about 20 per cent of the upper half and 20 per cent of the lower half in one exposure. However, fine root defects were not detected by this method.

TABLE 2 — CHEMICAL REQUIREMENTS

Identification symbol	TP 304	TP 309	TP 310	TP 321	TP 347	TP 316	TP 317
Grade	Chromium-nickel	Chromium-nickel	Chromium-nickel	Chromium-nickel-titanium	Chromium-nickel-columbium	Chromium-nickel-molybdenum	Chromium-nickel-molybdenum
Carbon, max., per cent	0·080	0·150	0·150	0·080	0·080	0·080	0·080
Manganese, max., per cent	2·000	2·000	2·000	2·000	2·000	2·000	2·000
Phosphorus, max., per cent	0·030	0·030	0·030	0·030	0·030	0·030	0·030
Sulphur, max., per cent	0·030	0·030	0·030	0·030	0·030	0·030	0·030
Silicon, max., per cent	0·750	0·750	0·750	0·750	0·750	0·750	0·750
Nickel, per cent	8·0-11·0	12·0-15·0	19·0-22·0	9·0-13·0	9·0-13·0	11·0-14·0	11·0-14·0
Chromium, per cent	18·0-20·0	22·0-24·0	24·0-26·0	17·0-20·0	17·0-20·0	16·0-18·0	18·0-20·0
Molybdenum, per cent	—	—	—	—	—	2·0-3·0	3·0-4·0
Titanium, per cent	—	—	—	*a*	—	—	—
Columbium, per cent	—	—	—	—	*b*	—	—

a The titanium content shall be not less than five times the carbon content and not more than 0·60 per cent.

b The columbium content shall be not less than ten times the carbon content and not more than 1·00 per cent.

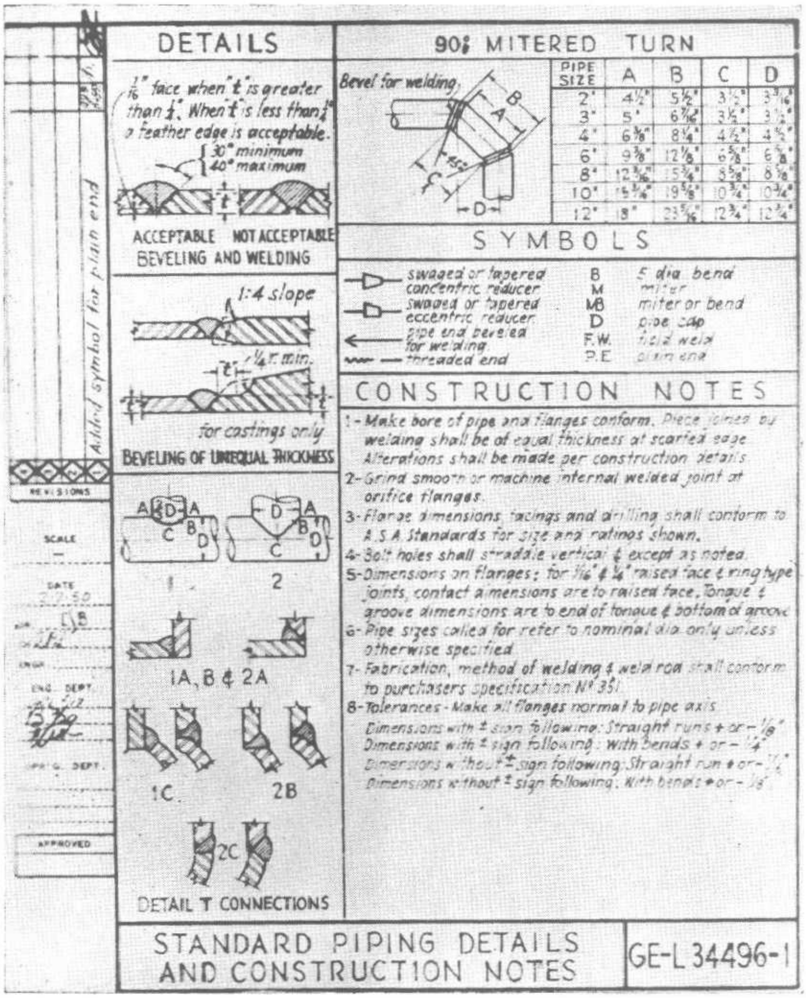


FIG. 6 — STANDARD PIPING DETAILS

In refinery construction, materials used for fabricated austenitic chrome-nickel steel piping must conform to the requirements of the A.S.A. Code for pressure piping, or the A.S.M.E. Boiler Code. Fig. 6 shows standard piping detail as used for refinery construction.

Table 2 shows the chemical requirements as specified by the A.S.T.M. under A312-51T.

The following tabulation shows the electrodes to be used for the various types of steel, as per A.S.T.M. A298:

A.I.S.I.	*A.S.T.M.*	*Electrode*
304	A312 TP 304	308, 309, 310, 316
304 ELC*	As above with modified carbon content	308, 316 (ELC), 347
316	A312 TP 316	316
316 ELC	As above with modified carbon content	316 ELC
317	A312 TP 317	316, 317
317 ELC	As above with modified carbon content	316 ELC, 317 ELC

*ELC = Extra Low Carbon, 0·03 per cent max.

A.I.S.I.	*A.S.T.M.*	*Electrode*
321	A312 TP 321	347, 308 ELC
347	A312 TP 347	347, 308 ELC

Fusion welding of piping shall conform to paragraph U68 of the A.S.M.E. Unfired Pressure Vessels Code for weld preparation, type of joint, radiographic inspection and stress-relieving. It shall also conform to paragraph A155 of the A.S.T.M. Specifications for hydrostatic testing, thickness and weight, permissible variations in dimensions, length, ends and finish.

Flanges and welding fittings shall correspond in composition to that of the pipe to which they will be attached in conformance with A.S.T.M. Specification A182 as shown in Table 3.

Forged steel fittings such as ells, tees, caps, etc., shall be fabricated as per A.S.T.M. Specification A234, but the composition must correspond to that of the pipe to which they are attached and shall have been solution heat-treated by liquid-quenching from 1900°F.

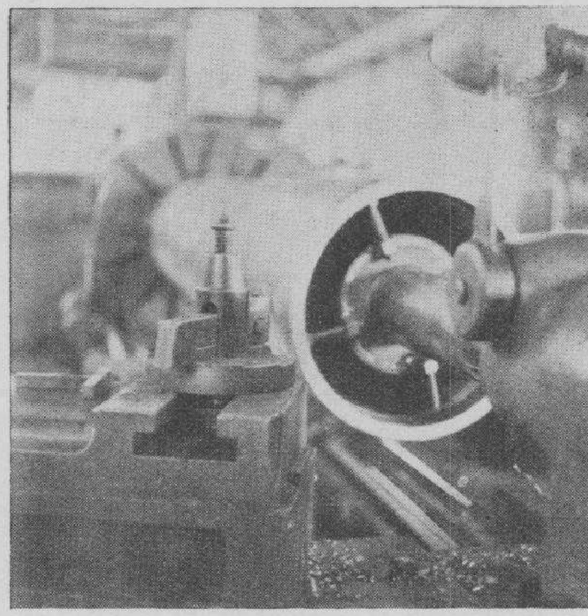


FIG. 7 — CUTTING

Requirements for Laying out, Cutting and Fitting

Cutting shall be accurate and smooth, true to templates and bevelled as specified in the piping detail sheets (*see* FIG. 6). Cuts may be made by machine, by the Linde Powder Cutting Process or the Arcos Oxyarc

TABLE 3 — CHEMICAL REQUIREMENTS FOR AUSTENITIC STEELS

Identification symbol	F 304	F 316	F 347	F 321	F 10	F 310
Grade	18 chromium-8 nickel	18 chromium-8 nickel modified with molybdenum	18 chromium-8 nickel modified with columbium	18 chromium-8 nickel modified with titanium	20 nickel-8 chromium	25 chromium-20 nickel
Carbon, per cent	0·080 max.	0·080 max.	0·080 max.	0·080 max.	0·10-0·20	0·150 max.
Manganese, per cent	2·000 max.	2·000 max.	2·000 max.	2·500 max.	0·50-0·80	2·000 max.
Phosphorus, max., per cent	0·040	0·040	0·040	0·035	0·030	0·040
Sulphur, max., per cent	0·030	0·030	0·030	0·030	0·030	0·030
Silicon, per cent	1·000 max.	1·000 max.	1·000 max.	0·850 max.	1·00-1·40	1·000 max.
Nickel, per cent	8·00-11·00	10·00-14·00	9·00-12·00	9·000 min.	19·00-22·00	19·00-22·00
Chromium, per cent	18·00-20·00	16·00-18·00	17·00-19·00	17·000 min.	7·00-9·00	24·00-26·00
Molybdenum, per cent	—	2·00-3·00	—	—	—	—
Columbium, per cent	—	—	*a*	—	—	—
Titanium, per cent	—	—	—	*b*	—	—

a Grade F 347 shall have a columbium content of not less than ten times the carbon content and not more than 1·00 per cent.

b Grade F 321 shall have a titanium content of not less than five times the carbon content and not more than 0·60 per cent.

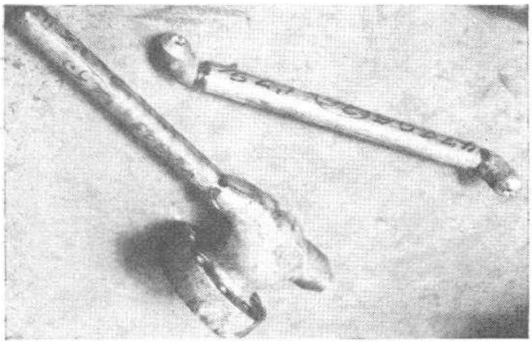


FIG. 8 — FITTING

Process (FIGS. 7 and 8). Bevels shall be machined or ground after flame or arc cutting, removing at least $\frac{1}{16}$ in. of metal.

Spacing of every joint shall be such as to obtain full penetration throughout.

Small *tack welds*, penetrating to the bottom of the groove, shall be used in fitting up. If free from cracks, they may become a part of the finished weld. Cracked tack welds or large tack welds are not acceptable and shall be chipped or ground out before laying of the first pass.

Unless the use of *back-up strips* or rings is specified on the order or the piping detail sheets, the supplier shall obtain the approval of the purchaser for their use. Back-up strips or rings, when specified, shall be of the same material as the pipe and of design acceptable to the purchaser.

Welding Requirements

Qualifications — Before commencement of fabrication, the supplier shall make available for review by the purchaser's inspector, satisfactory evidence showing the qualification of welding procedures and welding operators (FIG. 9).

Welding Processes — Welds shall be made either by the electric arc, the inert-gas metal arc or atomic hydrogen process. Combinations of these are acceptable, i.e. first bead may be inert-gas metal arc followed by electric arc. Oxy-acetylene gas welding is not acceptable.

Welding Procedure — Every weld shall have full thickness penetration throughout. Excessive accumulation of slag and welding dross on the inside surface of welds shall be removed. In multiple-layer welds, the slag shall be cleaned from each layer of weld metal and any defect which would affect the strength and soundness of the weld shall be chipped or ground out before the next layer is applied. Slag and spatter shall be removed from all surfaces of the completed weld. Butt welds shall have a reinforcement of approximately $\frac{1}{16}$ in. and the edges of all welds shall be free of undercutting.

Mitre Bends — Wrought welding fittings are preferred, but when mitre bends must be used, welds on the inside radius shall be made with a uniform curvature. Welds with sharp corners or undercutting are not acceptable. Gusset plate reinforcements shall not be used unless specifically detailed in the piping detail sheets.

Reinforcing — Reinforcing of branch connections, wyes, etc., shall be applied only as specified on the order or the piping detail sheets. All reinforcement pads shall be of the same composition as the pipe and each shall be provided with a vent hole tapped for $\frac{1}{8}$ in. pipe. Welds to which reinforcement is to be applied shall be inspected by the purchaser's inspector before application of the

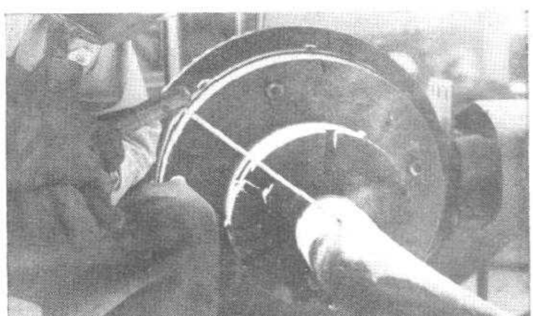


FIG. 9 — QUALIFICATION OF WELDING PROCEDURES AND WELDING OPERATORS

reinforcement. Welds with reinforcement pads shall be tested with air through the vent hole in the pads at a pressure and for a period specified by the purchaser's inspector and the welds thoroughly painted with soap suds. Leak welds shall be repaired by the supplier to the satisfaction of the purchaser's inspector and retested. Upon completion of all fabrication and testing, the vent holes in all reinforcement pads shall be left *unplugged*.

Bending Requirements

All bends shall be smooth and free from flat spots, corrugations and indentations. Flattening of the cross-section of bends shall not be greater than 7½ per cent of the nominal pipe diameter. When the requirements are such that the allowable flattening must be less than this, the order shall state the degree of flattening permitted.

Bends may be made hot or cold. It is recommended that heating for hot bending be below 1000°F., but not over 2000°F. Working of these materials at temperatures between 1000° and 1700°F. should be avoided.

Heat-treating Requirements

All welded joints, and all bends and other parts worked either hot or cold shall be stress-relieved as prescribed. Fig. 10 shows heat-treating furnace as used by the Associated Piping & Engineering Company Inc., of Compton, California.

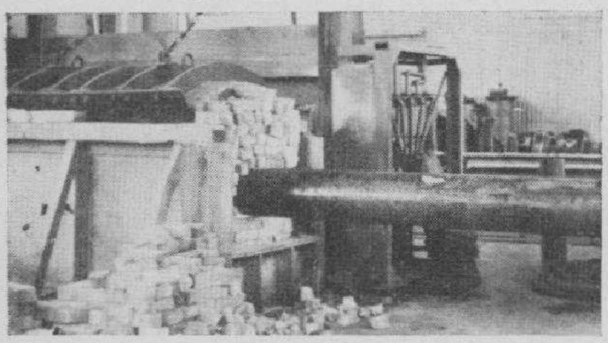


FIG. 10 — HEAT-TREATING FURNACE

Specific requirements for all except ELC grades:

Initial heating of the metal shall be at a slow rate, not less than ½ hr. to 1000°F. Subsequent heating may be at any convenient rate.

Temperature for stress-relieving shall be at 1550°-1600°F. followed by cooling in still air.

All pieces shall be held at temperature for 2 hr. per inch of thickness, but not less than 2 hr.

Flame impingement shall be avoided.

The metal temperature shall be reasonably uniform throughout the section of each piece being heat-treated. Temperatures shall be determined by attaching thermocouples to representative portions of the work.

Specific requirements for ELC grades are the same as above except temperature should be held in the range 1200°-1250°F.

Hydrostatic Testing

When specified on the piping detail sheets, fabricated piping shall be hydrostatically tested for a period specified by the purchaser's inspector at the specified pressure in the presence of the purchaser's inspector. All defects observed during the test shall be repaired by the supplier at his expense to the satisfaction of the purchaser's inspector and retested.

Radiographing

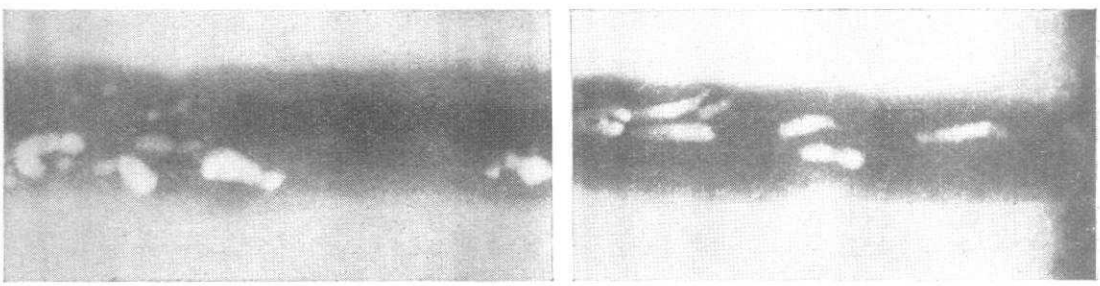
Purchaser's inspector shall have the privilege of radiographing any weld at purchaser's expense. However, when specified on the piping detail sheets, welds made by the supplier shall be radiographed at his expense. All defects, considered by the purchaser's inspector to affect the strength and soundness of the weld, shall be repaired by the supplier at his expense to the satisfaction of the purchaser's inspector. All

FIG. 11 — STANDARD RADIOGRAPHIC SET-UP

radiographic inspection shall conform to the requirements of paragraph UW-51 of the A.S.M.E. Code for Unfired Pressure Vessels or paragraph P-102h of the A.S.M.E. Code for Power Boilers. Fig. 11 shows a standard radiographic set-up in a pipe fabrication shop using a radioactive isotope. Figs. 12 and 13 show a number of typical defects found in pipe welding.

The development of synthetic radioactive materials by the U.S. Atomic Energy Commission has been a major factor in the progress of the American welding industry. Not until recent years could small fabricators afford their own radiographic inspection facilities or outside inspection and weld control services. Radioactive materials are relatively inexpensive when compared to an X-ray machine installation, and these isotopes are also extremely portable. Wherever a weld can be made it can be inspected with isotopes. Until recently cobalt 60 was the only isotope used for weld inspection. However, since late in 1954, cesium 137 — which has a 33-year half-life period, and renders improved radiographs — has been gradually replacing cobalt 60 except for very heavy steel sections.

Without a doubt, more new isotopes will be developed in the future with even longer half-life periods, and the metallurgist will have available radioactive sources of suitable wave-lengths for the nondestructive testing of almost all materials.



FIGS. 12 & 13 — TYPICAL DEFECTS