Welding of High Pressure Steam Pipe

By J K AHLUWALIA*

Steam pipelines are subjected to high operating conditions, and in order to satisfy the exacting requirements of these conditions, and to overcome the hazards and numerous difficulties encountered for successful operation, special techniques have to be adopted.

As the steam pressure and temperature increase, it becomes increasingly difficult to handle the material to be used and acceptance standards tend to become higher. The amount of non-destructive testing carried out is extensive but the repetitive nature of the work allows for a considerable degree of standardisation of inspection methods.

Material

The selection of materials is based on their properties at the operating temperature. Modern power plant operates at steam temperatures ranging between 850°F and 1100°F. At these temperatures, the governing factor is the creep strength of the material.

In olden days, engineers used to base their designs on the short-time tensile tests carried out at room temperature, when yield point and the ultimate tensile strength so obtained do not alter appreciably within the duration of the test.

In conditions of continuous operation at high temperatures, however, a different state of affairs obtains. For example, a mild steel with an ultimate tensile strength of 28 tons per square inch and 36% elongation when tested at room temperature, and approximately 20 tons per square inch ultimate tensile strength and 38% elongation at 900°F., as measured by normal short time tests, would fail at this temperature under a stress of merely 6 tons per square inch in 100,000 hours with practically no ductility.

The measurement of creep properties is necessarily a time-consuming affair, and during the last 30 years, a tremendous amount of work has been done in measuring the creep strength of existing steels, the effect of heat treatments and composition and in the development of new alloys to meet more exacting conditions.

Early work showed that the addition of 0.5% molybdenum to a carbon steel, greatly improved its creep properties and this steel has been extensively used for high temperature steam plant in the range 750°F to 900°F. A further improvement in high temperature properties has been found to be effected by the addition of vanadium. 0.5% molybdenum and 0.25% vanadium steel is used for steam plant in the range of 900°F to 1050°F.

Carbon molybdenum steel is used extensively for forgings and castings for high temperature steam conditions, but for pipe work, chromium molybdenum steel is generally used.

It is fortunate from the welding point of view, that the creep resistance of the steel improves as the carbon content is reduced. The hardenability of steel being less, the danger of weld junction cracking is diminished. In practice, the maximum allowable carbon content of chrome molybdenum steel is 0.15%.

The creep properties of these steels are also affected by the heat treatment applied to them and, for maximum creep resistance, pipes should go into service in the normalised or normalised and tempered conditions.

The high temperature conditions under which most of these pipes have to operate involve peculiar hazards and certain precautions foreign to normal welding shop practice have to be taken. For example, no stamping of identification numbers is allowed to be carried out on the finished pipes, because of the possible danger of initiating cracking from the points of stress concentration so formed. Because of the danger of intercrystalline penetration by molten metals, lead-based paints are not used.

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Electrodes and Filler Rods

In general, electrodes and filler rods are used which deposit weld metal similar in chemical composition to that of the parent materials and having mechanical properties at least equal to the minimum specified for the parent material. Sometimes for chromium molybdenum pipes, however, plain molybdenum bearing steel electrodes are used as their relative ease of welding offsets any possible loss of creep strength as compared with chromium molybdenum steel.

The choice of a particular type of electrode is based on general weldability related to the actual technique adopted.

Welding Methods

The majority of joints are made by manual metal arc welding. Small bore pipe joints are however preferably made by oxy-acetylene process. Metal arc welding on root runs by oxy-acetylene and by inert gas tungsten arc processes are also used. Some restricted use is made of automatic and semi-automatic methods.

The conventional preparation for metal arc welded butt joints involves the use of backing rings. Backing rings are usually considered necessary in order to ensure adequate penetration without forming undesirable protrusions which are difficult to avoid with open butt joints.

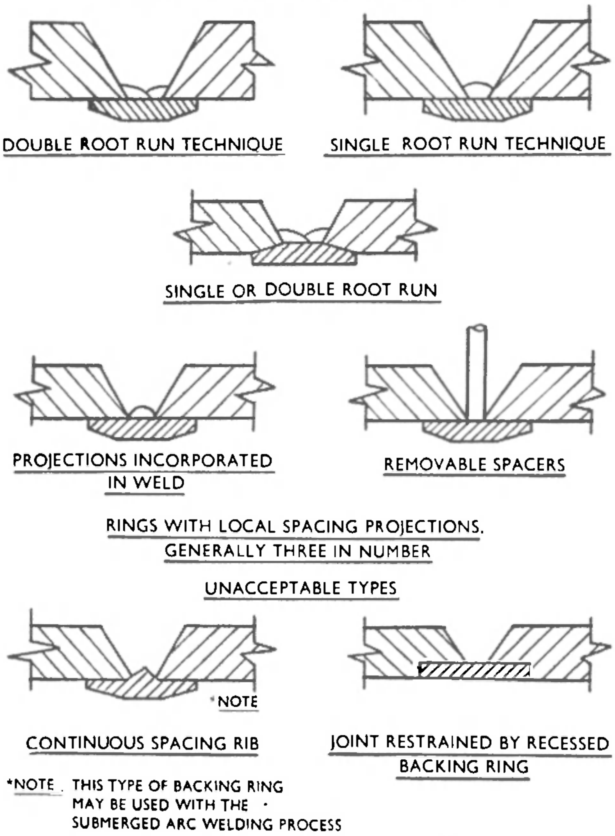
Backing rings help a great deal in securing accurate alignment of the pipe joints. Backing rings are however a potential source of basal weld troubles, owing to the formation of stress raisers at the junction of the pipe and the ring at the bottom of the weld. To overcome this difficulty, a number of designs have been proposed for joint preparations involving the use of various shaped and fitted rings. Some typical ones are shown in figure 1.

Consumable backing rings, shell-moulded sand backing rings and ceramic coated backing rings are new developments to overcome this problem. We have used consumable inserts quite extensively and find that by using inert gas tungsten arc process with back purging for root runs, welds of very high quality are obtained. We have also used with advantage the 'J' preparation. This preparation is illustrated in figure 2.

In this process, pipe ends are butted together with no root gap and inert gas tungsten arc process with back purging is employed for the root run. This process is, however, more suitable for shopwelds, because perfect alignment is necessary to obtain complete fusion. For site welds where joints are assembled in situ, such accuracy in alignment is not practicable.

FIG. 1

PERMANENT BACKING RINGS—ACCEPTABLE TYPES

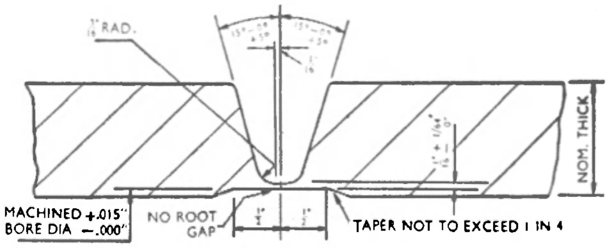


Welding Technique

Following welding techniques are employed (see figure 3).

a) Rolling through 360°—Down hand technique.
b) 180° turn—Vertical Up Technique.
(c) Vertical Up Technique.
d) Horizontal-Vertical Technique.
e) Vertical Down Technique.

FIG. 2



Heat Treatment

Preheating and post-heating are essential with high pressure pipe welds.

a) *Preheating :* With oxy-acetylene welds, preheating materially eases the task of welding the first run on a thick walled pipe. The main effect of preheating is to reduce the temperature gradient between the weld and the surrounding parent metal, which in turn retards the cooling rate of the weld. The contraction stresses set up as the weld metal cools can only be reduced by plastic flow chiefly in the high temperature range, and a high preheat temperature allows relatively greater plastic deformation to take place, thus reducing the final contraction and internal stress.

The two greatest hazards in pipe welds are basal cracking and weld junction cracking. It is generally agreed that basal cracks form at relatively low temperatures and as retardation in cooling rate due to preheating is most marked at low temperatures, preheating greatly reduces the tendency to this form of cracking.

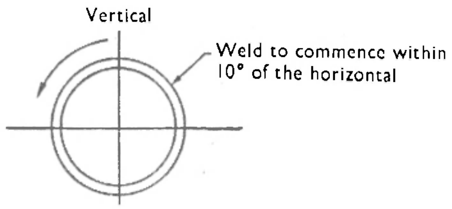
Junction cracking results from the imposition of high weld stresses on the hard boundary layers formed during the rapid cooling of the weld metal. The slower the rate of cooling through the transformation range of the steel, the softer will be these junction layers. It has been shown for example that a preheat temperature of 200°C reduces the cooling rate in the transformation range by approximately 35%, which would have a material effect on the hardness of the boundary layers and hence on its susceptibility to crack formation.

When dealing with thin sections of mild steel both temperature gradients and the hardenability of steel are low and successful welds can be made without any preheat. As the section thickness increases, the chilling effect becomes greater and as alloy additions are made, the hardenability of the steel increases so that with heavy sections of alloy steels, preheating to a reasonably high temperature becomes essential. Table I gives recommended temperatures for preheat of various steels.

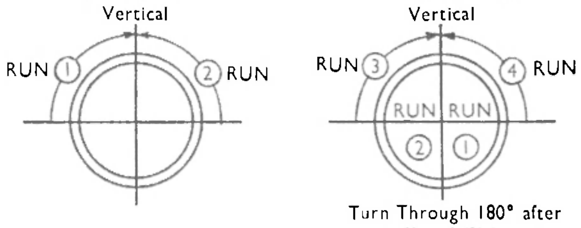
The preheating temperatures are maintained throughout the welding operations and the weld is then heated for stress relieving without being allowed to cool as a precaution against the formation of cracks.

b) *Post-heating :* Post-heating after welding generally comprises of a stress-relieving cycle, i.e. heating the steel to a temperature at which its yield point is low enough to allow relief of internal stresses by plastic strain. The recommended temperatures and times for stress relief are given in Table II.

FIG. 3

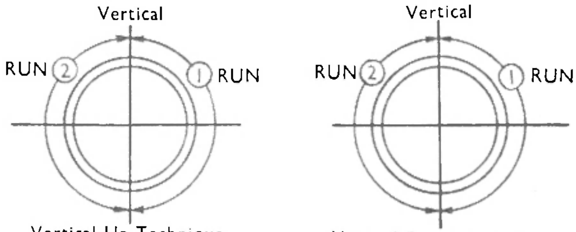


Rolling Through 360° Downhand Technique
(For Pipes Horizontal and Rolled During Welding)



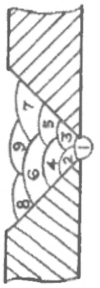
Turn Through 180° after runs (1) and (2) have been deposited

180° Turn Vertical Up Technique
(For Pipes Horizontal and Turned Through 180° During Welding)



Vertical Up Technique
(For Pipes Fixed Horizontally)

Vertical Down Technique
(For Pipes Fixed Horizontally)



Horizontal Vertical Technique
(For Pipes Fixed Horizontally)

Preheating and post-heating are carried out by methods which provide uniform heat over a peripheral band of metal of a minimum width of 3 times the width of the weld. Portable muffle furnace, induction coils and resistance heating finger elements are generally used on site work. Temperatures are measured by thermocouples attached to the pipe at appropriate positions.

In shop work where many more welds are being carried out at one time, stationary industrial furnaces are used for post-heating.

TABLE I

Type of steel	*Electric arc welding*		*Oxy-acetylene welding*		
	Th above which preheat is required	*Minimum preheat temperature*	*Thickness* *Over 7/16" uti 11/16"*	*Over 11/16" uti 7/8"*	*Over 7/8"*
Carbon uti 0.26%	3/4" & over	100°C	100°C	200°C	300°C
Carbon over 0.26% uti 0.40%	all	150°C	do	do	do
Carbon ½% Mo	all	do	do	do	do
1% Cr ½% Mo	all	do	do	do	do
1¼% Cr ½% Mo	all	do	do	do	do
2¼% Cr 1% Mo	all	200°C	do	do	do
½% Cr ½% Mo ¼% V (pipes)	all	do	do	do	do

Carbon steel-pipes are cooled from the stress relieving temperature under asbestos wraps to a temperature of 500°C and thereafter cooled in free air.

Alloy steel pipes are slowly cooled from the stress relieving temperature to temperature of 500°C at the rate of 100 to 150 C per hour and thereafter cooled in free air.

Where furnace stress relieving is employed, pipework is not withdrawn from the furnace before its temperature has fallen to 500°C from which temperature it is cooled in free air.

Pipe welds made by oxy-acetylene process are normalised by heating to a temperature of 900—930°C followed by cooling in air. Normalising refines the structure, improves the mechanical properties and relieves the internal stresess of the welds.

Welders

A very high standard of welding proficiency is required for this type of work. Once a suitable welding technique has been developed, reliance has to be placed on the welders to produce consistently sound welds. It is therefore necessary to choose the welders carefully to train them in the work until the required proficiency has been attained and to provide adequate supervision throughout all production work.

Welding tests as laid down in Chapter XIII of the Indian Boiler Regulations are mandatory and all the welders to be employed on this work have to carry out such tests to the satisfaction of the appropriate Inspection Authority before being allowed to proceed with any work and to undergo similar retests at intervals. Each welder is required to produce test welds in the materials and by the process to be employed in production, i.e. metallic arc, oxy acetylene, inert gas tungsten arc, etc.

Welding is carried out with the test pieces in fixed positions and the welding procedure including heat treatment is carried out exactly as for production welds. Welds are subjected to the following examinations.

1. *Visual inspection* : to see the surface finish of the weld and whether any undercuts and cracks are present.

TABLE II

Type of steel	*Stress relieving temperature*	*Time at temperature per inch of thickness : local stress relief : Welds*
Carbon uti 0.26%	580°C-620°C	1 hour : min ½ hour
Carbon over 0.26% uti 0.40%	630°C-670°C	Do
½% Mo	630°C-660°C	1 hour ; min 1 hour
1% Cr ½% Mo	630°C-670°C	1 hour : min ½ hour
1¼% Cr ½% Mo	Do	Do
2¼% Cr 1% Mo	660°C-690°C 700°C-750°C	Do
Cr Mo V ½% ½% ¼% (pipes)	650°C-710°C	Do

2. *Macro-examination :* Sections are cut from the welds and macro-examination is carried out on polished and etched cross-sections. Macro-examination reveals the presence of very small basal cracks, lack of fusion, porosity and slag inclusions.

3. *Radiographic examination :* Radiographic examination is carried out in buttwelds. Radiographic examination gives an overall picture of weld cleanliness, showing any entrapped slag, porosity, lack of penetration and macro cracks.

4. *Controlled bend tests :* Bend tests with (i) root of the weld in tension and (ii) face of the weld in tension are carried out on sections cut out from buttwelds. These tests give adequate information on the ductility of the weld metal and heat-affected zones. The presence of any basal defects is revealed by premature cracking.

5. *Tensile tests :* Tensile tests taken across the weld are generally carried out for procedure tests. With the welds such as we are considering, weld metal is stronger than the parent metal. The fracture therefore always occurs on the latter unless major defects are present in the weld and such defects would be more rapidly revealed by bend tests. The tensile tests therefore do not offer much useful information.

6. *Non-destructive testing :* In spite of all the above precautions taken to ensure good quality welds, it is advisable to carry out non-destructive testing of production welds. There are at present three types of non-destructive testing in use for the examination of welds of this type :—(a) ultra-sonic examination, (b) magnetographic method and (c) radiography.

Ultra-sonic testing : When conditions are suitable this offers an extremely sensitive method of examination for internal defects. Sound waves emitted with frequencies greater than 20,000 cycles per second are inaudible and are known as ultra-sonic. In the ultra-sonic method of flaw detection, such sound impulses are produced at frequencies of 2,000,000 to 10,000,000 cycles per second, usually in short bursts of 20 to 50 cycles at a time, by means of piezoelectric crystals. If these ultra-sonic waves are introduced into the steel specimen by coupling the oscillating crystal to the steel surface by means of some liquid such as oil, jelly or water, they can be made to travel through the material and can be picked up on the other side by a similar crystal. It is customary to display the received signal on the cathode-ray oscillograph. If there is a defect in the path of the waves, it will send back an echo towards the side from which the signal was transmitted which can be picked up by another (or the same) crystal probe. There is also an echo received from the opposite face of the specimen and the display on the cathode-ray tube then consists of the starting signal and back echo when no flaw is present, but of the starting signal and flaw echo and back echo, in that order when there is a flaw. The position of the flaw relative to the front and back face can therefore be determined and the type of blip, its shape and movement when probes are moved give much information as to the shape, size, position and orientation of the flaw. This method, however, is still in the development stage. Unfortunately, the configuration of the base of the weld, particularly when a backing ring is used, presents a difficulty in the development of this method.

Magnetographic method : It is the well-known method of crack detection. The portion of the workpiece under examination is firstly magnetised by an electromagnet. Magnetic iron oxide in a suitable vehicle, e.g. paraffin, is then poured over the area. Any surface cracks are revealed by the oxide building up in them and so revealing their presence. Cracks indiscernible to the naked eye are revealed by this test. By imposing a very high current it is possible to detect flaws at some distance below the surface, such flaws being shown by the surface pattern produced as in normal crack detection. The method is not very sensitive and results are rather difficult to interpret.

Radiography : Both the above methods suffer from the disadvantages of being too dependent on the skill and experience of the operator and of the difficulty of producing permanent records. Radiography, on the other hand, is relatively simple to carry out and a permanent record is produced which can be examined by various inspecting authorities. Electromagnetic radiations (for example, X-rays or gamma-rays) are made to pass through the specimen to be examined and are absorbed to varying extents according to the thickness and density of the specimen. They are then allowed to fall on a photographic plate and after development the resultant "shadow graph" shows the position and extent of variations in density caused by irregularities, imperfections or defects.

Radiography is one of the best methods for detecting defects, such as lack of penetration, blow holes, slag inclusions, undercutting, etc. which commonly occur in fusion welds. On the other hand, where fine cracks are concerned it is almost useless. For example, in the case of a crack, it is only the amount of the crack which is actually in line with the beam of radiation which affects the amount of radiation passing through. This crack width usually requires to be at least 1% of the thickness of the material being examined for it to give a sufficient contrast to be seen on the resulting radiograph.

Two radiography techniques are available for the examination of pipe welds. A double wall technique can be used with the external source or a single wall technique with the source placed inside the pipe. For a double wall technique, the exposure times required with gamma ray sources are too long. The single wall technique is therefore preferred. In order to place the source at the centre of the pipe, two methods are available. When accessible, the source can be inserted from one end of the pipe. This can usually be accomplished in shop work. A crawler type of fitting based on umbrella principle is sometimes used for this purpose. In site work generally, such method cannot be used and it is then necessary to drill the pipe adjacent to the weld for insertion of a source holder, the hole being subsequently plugged and welded.

The two factors which make for good radiographs are high contrast and a good definition. The contrast of radiographs produced by gamma ray sources is inferior to those of the X-rays and the source to film distance when the gamma-ray source is placed at the centre of the pipe is often rather short to attain maximum definition. In spite of these apparent drawbacks, tests have shown that surprisingly good quality radiographs can be produced with Iridium 192 isotope under these conditions. Although of slightly inferior definition to those taken with greater source to film distances and of much less contrast than X-ray radiography, they appear to show up all the defects which might be expected to be seen by radiographs.

Gamma-rays are preferred to X-rays for the radiography of pipe welds, because of the expense of X-ray sets and the impracticability of handling and positioning them at site. Gamma-ray sources are comparatively very cheap. Artificial radioactive isotopes are produced at the Atomic Energy Establishment, Trombay in the atomic pile from elements such as cobalt, iridium and thulium. These radioactive isotopes emit radiations. The radiations emitted by different elements differ in their characteristics, allowing some choice of isotopes for the particular work required. For example, radiations from Thulium 170 have an energy of 85 kilovolts, whilst those from Iridium 192 have an energy of 600 kilovolts and those from Cobalt 60, an energy of 1200 kilovolts. The low energy source Thulium 170 is very suitable for the radiography of light alloys, while Cobalt 60 is capable of penetrating 6 inches of steel. The obvious choice of source for radiographing pipe welds is Iridium 192 which produces good radiographs with steel thicknesses of between 1/2" and 2". One slight disadvantage of Iridium 192 is its short active life. All radioactive elements decay logarithmically, but at differing rates, the rate of decay being specified by their half life period, i.e. the time taken for their strength to be reduced to half its original value. The half life of Iridium 192 is only 70 days which necessitates sources being frequently returned to Atomic Energy Establishment for reactivation.