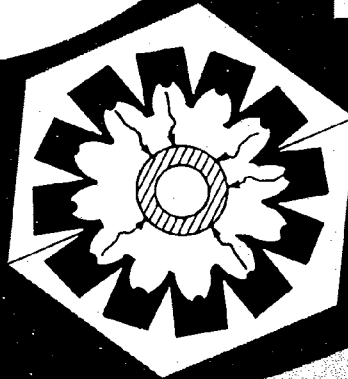
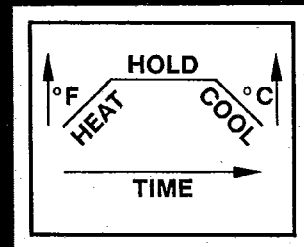


Recommended Practices for Local Heating of Welds in Piping and Tubing



American Welding Society

Keywords— Local heating, piping and tubing, heating methods, thermocouples, controls, insulation, preheating, postweld heat treating

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Recommended Practices for Local Heating of Welds in Piping and Tubing

Prepared by
AWS Committee on Piping and Tubing

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This standard provides information on equipment, temperature control, insulation, and advantages and disadvantages for the methods presently available for local heat treating of welded joints in pipe and tubing.



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Foreword

(This Foreword is not a part of ANSI/AWS D10.10-90, *Recommended Practices for Local Heating of Welds in Piping and Tubing*, but is included for information purposes only.)

This recommended practice is intended to supply useful information to those with a need to apply various heat treatments to welded pipe joints under circumstances which do not permit placing the entire weldment in a furnace or oven.

The first edition of the recommended practice prepared by the AWS Committee on Piping and Tubing was approved and published as AWS D10.10-75, *Local Heat Treatment of Welds in Piping and Tubing*.

The present edition of D10.10 has been revised to bring the document abreast of the present "state-of-the-art", and to reemphasize certain important topics; particularly, thermocouple selection and placement, proper provision for insulation, and use of the radiant heating methods.

Comments and suggestions for improving this recommended practice are welcome. They should be sent to the Secretary, Piping and Tubing Committee, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135.

A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures.

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Recommended Practices for Local Heating of Welds in Piping and Tubing

1. Scope

These recommended practices describe several methods of applying controlled heat to weld joints and a limited volume of base metal adjacent to the joints, as opposed to heating the complete weldment in a furnace or oven.

Detailed heating and cooling cycles for specific applications are not discussed since such requirements are usually a part of other codes and specifications.

2. General

2.1 Introduction. In the manufacture of weldments, it may be desirable to heat parts before welding (preheating) between passes (interpass heating), or after welding (postweld heating). Although it is not the intention of this publication to discuss the metallurgical reasons for such heating, it is useful to list the main reasons for these operations.

(1) The principal reason for preheating and interpass heating is to slow down the cooling rate of deposited weld metal and heat-affected zone. This both lessens the tendency to quench harden (where applicable), and increases the diffusion of hydrogen and other gases out of the weld metal and heat-affected zone.

(2) Postweld heat treating (PWHT) can have two beneficial effects, both of which occur simultaneously. One is the tempering of martensite that may have resulted from welding. This action restores ductility. The second is the reduction of residual stress, which is present in all welds. This action decreases the likelihood of premature failure and of distortion during subsequent machining operations. Postweld heat treatment may also increase corrosion resistance.

During shop manufacture, weldments are sometimes heated in a furnace. If the weldment exceeds the size of an available furnace or cannot be conveniently heated in a furnace (as in field fabrication), the weld and adjacent material may be locally heated by one of the methods

discussed in this publication. Although this document is directed primarily toward the heating of welds in piping and tubing, it can be used on other types of welded fabrication. The method used will often be determined by the availability of equipment, the accessibility of the area to be heated, and the type of heating operation to be performed (preheating, interpass heating, or post-heating).

Support for weldments may be necessary when parts are heated to elevated temperature and thereby lose strength. Without such additional support, there may be permanent distortion of an undesirable nature. (See 2.5.) Excessive heat loss may make it impossible to carry out a desired heating operation. Such heat losses can be produced by the presence of liquid or gases inside the pipe or tube.

Liquids, even in small amounts, can prevent the joint from reaching the desired temperature. It is necessary, therefore, to remove internal liquids and prevent the flow of liquids or gases inside piping which is being heated. In fact, all piping must be vented to assure that there is no pressure build-up, but this venting should be limited to prevent air from flowing through the piping, causing undesirable cooling of the pipe wall.

2.2 Measurement of Temperature. In heating operations, it is necessary to measure temperature. Visual determination of temperature by color without the aid of instruments should be avoided because of its lack of precision and its dependence on operator skill. Temperature-indicating crayons and paints, thermocouples, infrared instruments, bi-metallic switches, expansion bulbs, or other temperature sensitive devices can be used to monitor the temperature.

2.2.1 Temperature-Indicating Crayons and Paints. Temperature-indicating crayons and paints are of compositions which melt when the temperature exceeds the level for which they were designed. If a crayon or paint mark melts, the temperature is above that for which the crayon or paint is rated, but one does not know by how

much. By using a combination of such indicators, one can determine that the temperature is above the temperature of the mark which melts, and lower than the rating of another mark which does not melt. Of course, the surface of the work must be accessible for the use of these materials.

2.2.2 Thermocouples. If the ends of dissimilar wires are in contact with each other and also with a hot and a cold surface, a voltage difference between the two junctions is created. These voltage differences are proportional to the differences in temperature. Therefore, a properly calibrated instrument to measure the voltage difference can translate voltages into temperature readings at the hot junction. However, each combination of wires requires a separate calibration and an instrument designed for that combination.

A more complete discussion of thermocouples and their use is given in ANSI standard MC96.1, *Temperature Measurement Thermocouples*.¹ Of the seven combinations of thermocouple wire classified and discussed in this document, three are commonly selected for PWHT operations. Their classification, nominal composition, upper temperature limits, and color coding are shown in Table 1.

Table 1
Thermocouple Data

Type	Nominal Composition	Normal Upper Temperature Limit	Color Code:	
			Positive	Negative
J	Iron-Constantan	1400° F (760° C)	White	Red
E	Chromel-Constantan	1600° F (870° C)	Purple	Red
K	Chromel-Alumel	2300° F (1260° C)	Yellow	Red

The letter designation applies only to the temperature-voltage relationship and not to the material. This is done to eliminate the use of proprietary names.

Thermocouple wires are available in different gages. The thinner the wire, the faster the response to changes in temperature, but the shorter the life. The size of wire commonly used in local heating is #20 American Wire Gage (AWG), which has a diameter of 0.032 in. (.81 mm). If thermocouples are used only a few times, as is true in local heating, there is no incentive to select heavier gage wires which are more expensive. The wires must be electrically insulated from each other and from any other

conductor, such as the metal being heated, except at the junction. Such separation is accomplished by a manufactured sheath, or added ceramic beads, or similar systems. It is important that the insulation withstand the temperatures to which it will be exposed.

2.2.2.1 Thermocouple Extension Wires. Usually, the temperature-measuring instrument is farther from the heated area than the length of the thermocouple, requiring a thermocouple extension wire to connect the thermocouple and the instrument. Thermocouple extension wires are either of the same composition as the thermocouples or designed to match the thermocouple system. In the ANSI designation system, thermocouple extension wires have the letter "X" included in their designation. For example, thermocouple J (iron-constantan) may use either thermocouple extension Type J or Type JX. Care must be taken to connect the positive side of the thermocouple to the positive side of the extension lead and the negative to the negative. To minimize the risk of incorrect connections, the color red is used for the covering on the negative side of both thermocouples and extension leads. The longer the lead, the greater its resistance. Many temperature-measuring systems will not tolerate a resistance greater than 100 ohms, which limits the length of the extension lead.

To maintain the correct temperature-voltage relationship, thermocouple extension wires should be protected from mechanical damage, moisture, and excessive heat. Care should also be taken to prevent short radius bends, cold working, and excessive flexing.

2.2.2.2 Potentiometers. The potentiometer balances the voltage it receives from the thermocouple system against a standard voltage within the instrument. This standard voltage is obtained from either a standard cell or a regulated constant voltage power supply. In the case of a portable instrument, there is a standard cell and a battery. The battery is calibrated against the standard cell and then used to determine temperatures. Such calibration should be performed not only when the instrument is first used, but also at regular intervals.

Stray alternating current, especially high frequency currents, can cause errors. These errors can be reduced by AC rejection filters in the input circuit of the instrument.

2.2.2.3 Thermocouple Insulation and Installation. Any recording or controlling instrument reads the temperature at the junction (short) between the thermocouple wires closest to the instrument. Therefore, the wires must touch each other only at the spot where the temperature is to be measured. At all other locations, the wires must be insulated from each other and from the pipe or tube being heated.

The hot junction must be at the same temperature as the surface whose temperature is being measured. This

1. ANSI/ISA MC96.1-82, available from American National Standards Institute, 1430 Broadway, New York, NY 10018.

requires that (1) it be insulated from external radiant heat, (2) the thermocouple wire be kept under insulation for approximately 8 in. (200 mm) to prevent heat conduction along the wire, (3) the thermocouple be protected from corrosive media, and (4) the hot junction must be in intimate contact with the surface whose temperature is being measured. Note that large errors can be caused if there is no intimate contact or the wires contact each other outside the hot junction.

Several methods are used to attach the thermocouple to the surface. Formerly, it was common to drill holes in the pipe or tube surface, install the wires, and carefully peen the hole shut. One method presently used is to attach each wire to the surface by capacitor discharge welding, with the wires in close proximity to each other (see Figure 1). This system provides positive feedback to the instrument in case a wire breaks or contact is lost at the junction. Another method is to weld small sections of tubing to the surface, insert the thermocouple, and carefully peen the tubing so it is held in intimate contact with the part to be heated (see Figures 2, 3, and 4). Any installation should be carefully inspected for proper attachment before insulation is applied to the junction.

2.2.2.4 Thermocouple Readings to Control and Record Temperatures. The voltages produced by the thermocouples are sent to two types of instruments (1)

temperature controllers, which have been programmed to shut off the heating source at a specific temperature or follow a specific heating rate, holding temperature and time, and cooling rate, and (2) recorders, which document the actual temperature at specific times during the heating cycle. It is recommended that there be at least one extra thermocouple attached at each location, since thermocouples may fail.

2.3 Thermal Cycle and Width of the Heated Band. The four parts of the thermal cycle that are controlled in heat treatment are the heating rate above a specified temperature, the specified heat treating or "holding" temperature, the time at the holding temperature, and the cooling rate to a specified temperature. They may be fixed by the requirements of codes, specifications, or procedures.

Some piping codes limit heating and cooling rates to prevent the excessive stresses produced by uneven expansion or contraction. The temperature gradients through the wall of the pipe from outside diameter to inside diameter and in the longitudinal direction produce these stresses. There is no way to eliminate such differences in temperature by local heating, no matter how slow the heating and cooling rates or how long the holding time. Whenever heat is applied to only one side of a wall, there will be a gradient through it, and the thicker the wall, the greater this gradient for a given heat

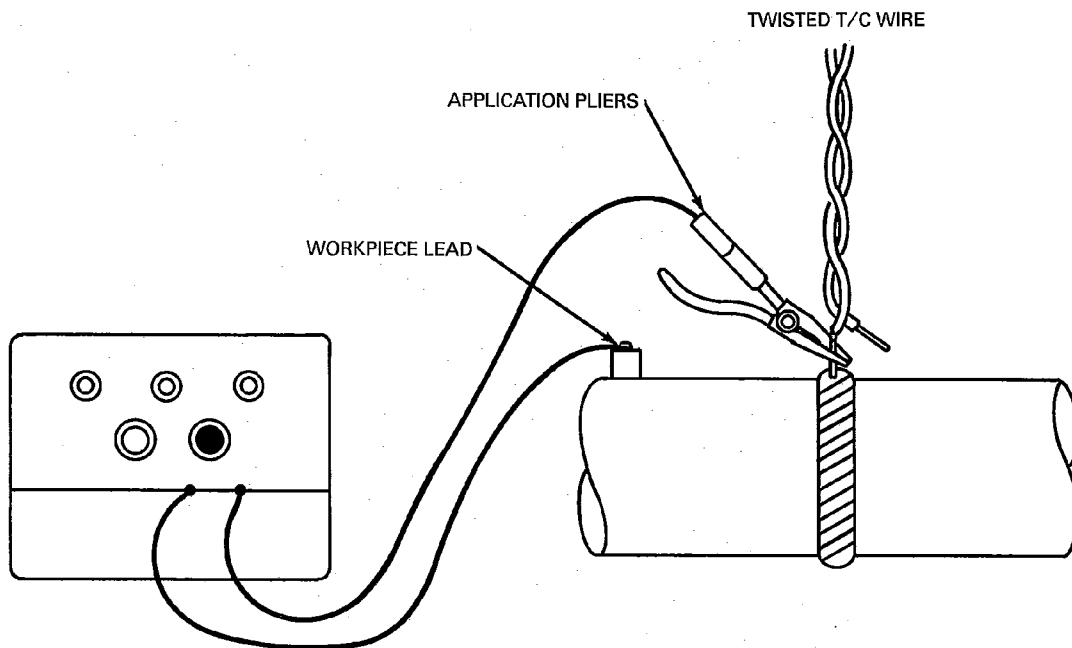
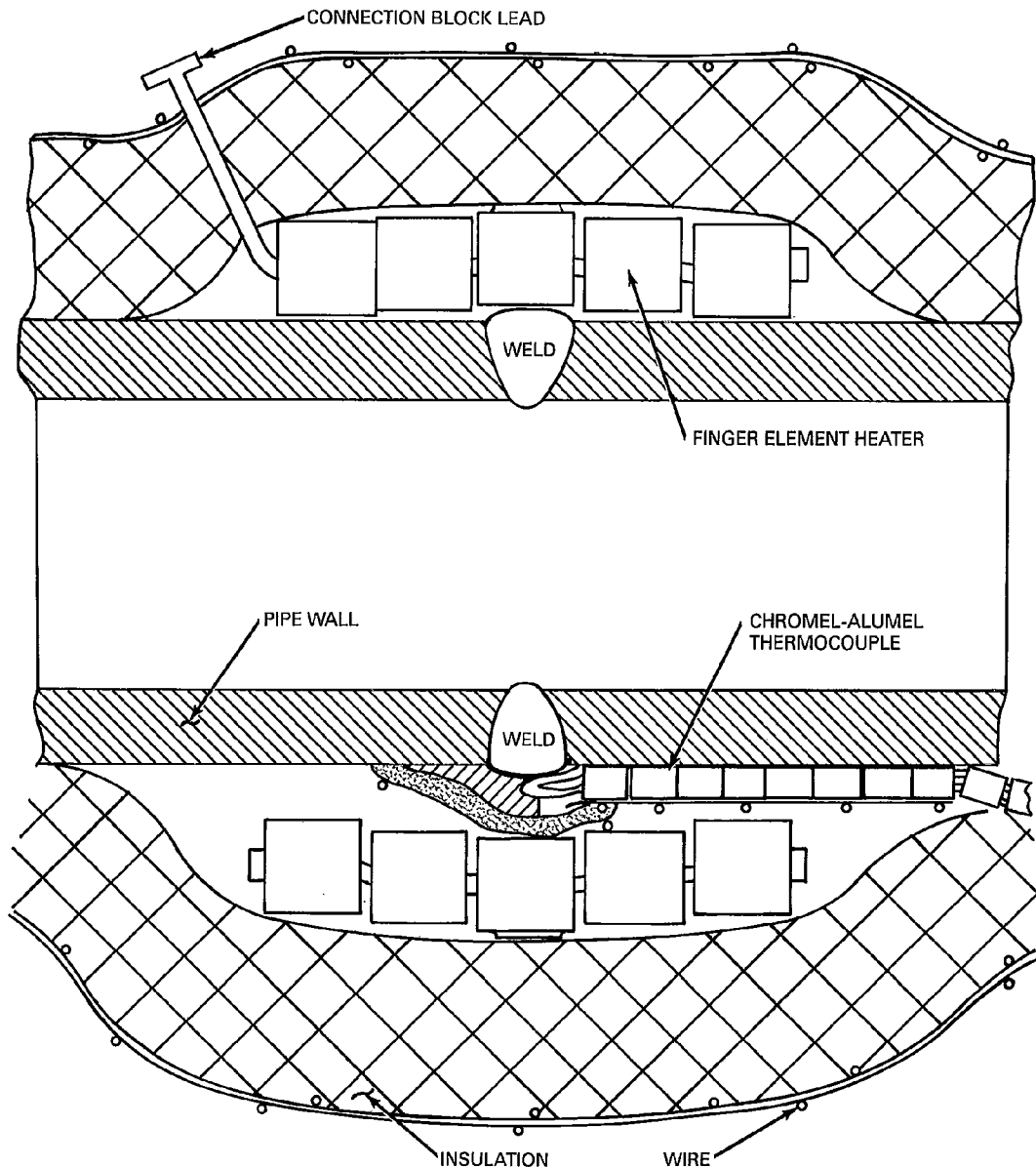


Figure 1 — Typical Thermocouple Attachment by Capacitor Discharge Welding



**Figure 2 — Typical Cross Section of Pipe Weld
Ready for Postweld Heat Treatment**

input. Experiments have shown that the through thickness temperature gradient is proportional to the width of the heated band on the surface, regardless of the thickness or diameter of the pipe and the type of energy source.

In general, the width of the circumferential band to be heated to the temperature range specified in the welding procedure should be at least five times the wall thickness of the thickest pipe (5t). For welds attaching nozzles,

lugs, etc., the width to be heated should be increased by the width of the attachment. Since specific requirements differ for different codes and specifications, the applicable documents should be consulted.

For example, with a wall thickness of 3 in. (76 mm), the width of the induction coils, resistance elements, radiant heaters, or any other source of heat should be at least 15 in. (381 mm) in order to keep the radial thermal gradients to a reasonable level. If the heat band is at least

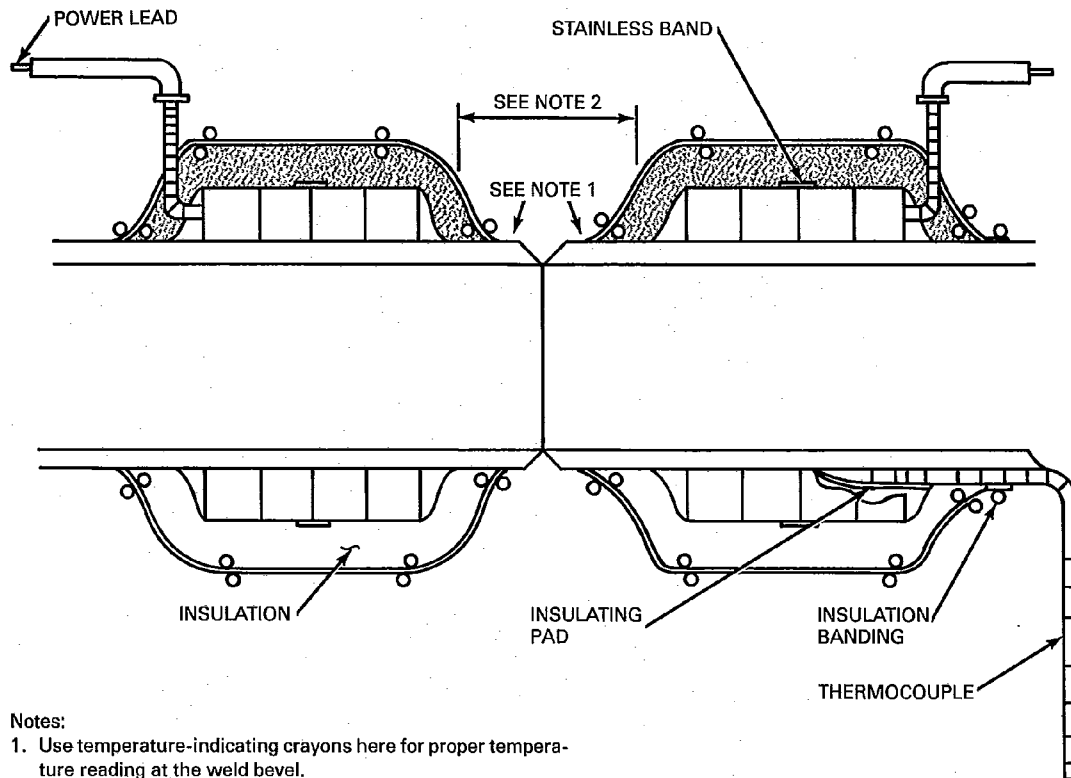


Figure 3 — Typical Setup for Preheating Pipe Welds Using Electric Resistance Finger-Element Heaters

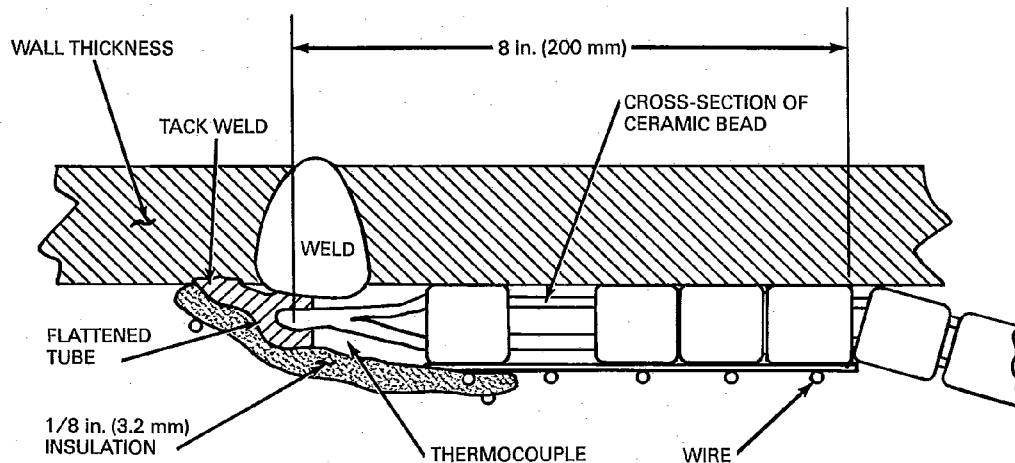


Figure 4 — Typical Thermocouple Attachment Using Flattened Tubing

5t wide, not only will the final temperature gradient from outside diameter to inside diameter be satisfactory, but also there will not be excessive gradients either radially or longitudinally as the pipe is brought up to the temperature of heat treatment.

Even with a heat source band width of 5t and adequate insulation, the radial gradient at holding temperature may be significant. Published research has shown that for thicknesses of 3 in. (76 mm) and 4-1/2 in. (114 mm), the gradient can reach 50° F (28° C) and 75° F (42° C), respectively. The heat treating procedure should make allowance for this range, and the temperature on the outside surface should be maintained near the maximum value allowed by the procedure. This measure will prevent the inside surface from becoming too cool.

During all stages of heat treatment, it is important that the temperature around the circumference be uniform. If local hot spots are created, these areas may become permanently distorted, cracked, or have their properties altered.

2.3.1 Heating Rate. The rate of heating can affect the temperature difference between outside diameter and inside diameter. The existence of a radial thermal gradient produces hoop stresses, with the outer fibers in compression and the inner fibers in tension, as the outer layers attempt to expand but are restrained by the cooler material below. The stresses are proportional to the temperature difference between outside diameter and inside diameter. As the heating rate increases, the temperature difference increases. However, so long as no cracking is produced, there is no harm done, since the stresses are relieved during the holding period.

Experiments have shown that the radial thermal gradient will not be excessive, regardless of heating rate, if the width of the heat band source is at least 5t. In any case, if the temperature difference across a pipe wall does not exceed 150° F (83° C), the hoop stresses will not exceed 20 000–21 000 psi (138–145 MPa) in either compression or tension. These stresses seem acceptable, so that any rate of heating which does not produce a gradient greater than 150° F (83° C) should be permissible, unless relevant codes specify otherwise.

2.3.2 Time at Temperature. The time at temperature and the specified temperature of PWHT, are related to specific material properties and intended service requirements. They are, therefore, beyond the scope of this document. Procedures which prescribe holding times in terms of hours per unit of thickness may well produce excessive holding times for thicker pipes and may not be required, unless relevant codes specify otherwise.

2.3.3 Cooling Rate. Stresses produced during heating are usually moderated during the holding time, while those produced during cooling tend to remain. The cooling rate may also affect mechanical properties such as

hardness and ductility. For this reason, the required rate of cooling may well be slower than the rate of heating. If slow cooling is required, the insulation should not be removed until the temperature is reached at which the heat treating procedure permits removal of insulation. Since the natural cooling rate is highest at higher temperatures, it may be necessary to continue applying heat during the early stages of cooling in order not to exceed the cooling rate. The external heat source can be removed or turned off at any time in the cooling cycle when the cooling rate equals, or is lower than, that required by the heat treating procedure. It should be noted that for some materials, an accelerated cooling rate is required to achieve specific properties.

2.4 Control of Heat Losses During Heat Treatment.

One aspect of local heating shared by all methods discussed in this publication is that of heat loss to the cooler, adjacent environment. Heat is lost by conduction through the heated structure itself, convection via moving air within the piping (the chimney effect), and radiation.

Without an internal heat source, nothing can be done to prevent heat losses within the structure, but insulation can be applied to the surfaces to prevent losses to the air. Convection losses can also be minimized by closing off the ends of the pipe and removing internal fluids or vapor.

Insulation with a high insulating value is preferred. Greater thicknesses of insulation will reduce heat losses and therefore are beneficial. The types of insulation most commonly used are mineral wool and ceramic fiber mats. Asbestos cloth is no longer used. For outer layers of insulation and along the pipe away from the heat sources, the application of glass wool insulation can be cost effective. However, glass wool insulation should not be allowed to be in contact with any heating element or any material hotter than 1200° F (650° C). Naturally, the greatest efficiency is achieved by insulating the hottest sections of pipe and extending the insulation well beyond the heated sections. A good rule of thumb is to have the insulation three times as long as the heated band. Some methods of heating, such as quartz lamps and infrared heaters, do not permit this since they heat by radiation to the pipe surface.

2.4.1 Mineral Wool. The least expensive type of insulation is mineral wool. Mineral wool can be used for preheating and postheating. Its thermal insulating properties are not as good as those of ceramic fiber mats, which means that more mineral wool will be required to do a given job. However, the lower cost of the mineral wool may offset the greater efficiency of the ceramic fiber mats. Mineral wool will deteriorate during postheat treatment and therefore will usually last for one heat treatment only. If mineral wool is used, rectangular pieces of mineral wool blankets should be cut and placed around the heater so the ends meet.

2.4.2 Ceramic Fiber Blankets. Ceramic fiber blankets or mats are more expensive than the other widely used types of insulation, but they have a much higher insulating value. Such mats are available with or without wire mesh reinforcement. The reinforcement protects the mats from mechanical damage during installation and also holds the insulation more securely in place during the heat treating operation.

Some industries and regulatory agencies have codes and specifications requiring ceramic fiber insulation to be encased in high temperature, tightly woven cloth in order to contain loose fibers. The cloth provides protection from inhalation of, and skin irritation by, the fibers. The useful life of the insulation is prolonged by the added protection of the cloth, but this benefit is offset because of the higher cost of this type of encased insulation.

If ceramic fiber mats are used, a single layer mat which is long enough to completely encircle the pipe and heaters, where the source of heat is under the insulation, should be used. Any inadvertent gaps should be filled with insulation. The mats can be secured in place with wire.

2.4.3 Asbestos Cloth. The use of asbestos cloth as an insulating material during heat treatment is specifically not recommended and may be prohibited by law due to health considerations.

2.4.4 Attachment of Insulation. Insulation pieces should be cut so that the ends either butt against or lap over themselves when the piece(s) are wrapped around the pipe. No gaps should be permitted in the insulation layer, and any inadvertent gaps should be filled with suitable insulation. Such wrapped insulation is usually held in place with wire. The wire should not be wrapped too tightly. Additional layers of insulation can be applied in special cases such as with heavy wall pipe or when the heat treating temperature is over 1200° F (650° C).

Insulation materials are often used temporarily to fill the open end of a pipe to eliminate internal drafts.

For induction heating, the insulation is placed between the pipe and the coils; for most other systems, such as resistance heating, the insulation is placed outside the heating elements. The insulation should extend well beyond the edge of the source of heat to diminish heat losses and assure a gradual thermal gradient from heated to unheated sections.

2.5 Support of Pipe During Heating. When metals are at elevated temperatures, their strength is lower than at ambient temperature. The weight of long pipe spans may be great enough to cause permanent bending when heating to typical postweld heat treatment temperatures if the weight is not supported externally. It is best to accomplish adequate support without the use of attachments welded to the pipe.

If cold springing has been used during assembly, the piping system should be supported during heat treatment. (Cold springing involves shortening the pipe during assembly to compensate for changes in length that occur during operation at elevated temperatures). To prevent loss of the "cold spring", all heat treatment of other welds in the "cold sprung" section of the piping system must be completed before making the final weld. Also, the pipe should be held in place continuously until both welding and heat treatment are completed.

2.6 Safety. Proper safety precautions should be taken in conducting all heat treating operations. Warnings or barriers should be provided to prevent unsuspecting personnel from contacting hot parts which would cause burns. The relatively high voltages used for some methods of heat treating require suitable precautions to be taken by operating personnel and provisions to ensure that there are no bare parts of electrical circuits exposed for personnel to contact. For those using welding machines as power supplies or bottled gas for heating, the reader should refer to appropriate parts of ANSI/ASC Z49.1, *Safety in Welding and Cutting*, latest edition. (See section 10.)

3. Induction Heating

3.1 General. In induction heating, alternating current (ac) is applied to coils wrapped around the steel parts to be heated. Because every electric current has a magnetic field associated with it, there is a magnetic field around the coils, and it penetrates the part around which the coils are wrapped. Since the current is alternating, the magnetic field also alternates in phase with it, sweeping through the part, collapsing, and then building up in the opposite direction. A current is thereby induced in the part because a current is produced in a part whenever there is a relative motion between a magnetic field and the part. Resistance to this induced current heats the part.

As the frequency of the current in the coil increases, the radius of the magnetic field associated with it decreases, and current is induced in the pipe to a lesser depth. If the frequency is high enough, only a thin skin is heated. Of course, heat will be conducted inward from this skin, so that in time the center will also be heated, but this may result in overheating the outside. Thus, high frequency should be avoided since neither stress relieving nor tempering is achieved unless the temperature of the inside surface of the pipe is close to the temperature of the outside surface, and both fall within the acceptable range specified by the welding procedure. The induction frequencies most commonly used in post weld heat treatment are 60 and 400 Hertz (Hz).

3.2 Effect of Composition and Temperature of the Pipe.

Materials capable of being magnetized tend to contain all of the magnetic field within their walls. If the material is not capable of being magnetized, lines of magnetic force will not be concentrated within it, and the magnetic field will then be distributed uniformly within the space occupied by air as well as metal inside the coils. When this is true, much more energy must be supplied to the coils to heat the metal, for the magnetic field in the air obviously will not heat the metal.

Carbon, low alloy, and other ferritic steels are magnetic below their Curie point, which is about 1400° F (760° C). They are nonmagnetic above that temperature. Austenitic stainless steels and most nonferrous metals are predominantly nonmagnetic at both ambient and elevated temperatures.

When the temperature of a magnetic material is increased above the Curie point and the lines of magnetic force are able to penetrate into the air space inside the pipe instead of being concentrated only within the pipe walls, there is less resistance to current flow in the coils. As a result, the current in the induction coils rises suddenly. For PWHT of magnetic materials above their Curie point and for all nonmagnetic materials, it is advisable to make the coils out of hollow tubes and pass water or some other coolant through them. Another consequence of having the magnetic field no longer concentrated only in the pipe is the need for increased energy

input to raise the temperature further. To accomplish this, more turns must be applied (as many as sixty instead of the usual ten or so), and the equipment must be capable of providing more energy.

3.3 Control of Heat Losses. (See 2.4) When the wall thicknesses of the parts on either side of the weld are not equal, such as where a thick-walled valve is joined to a pipe, the heat losses to the thicker part by conduction will be significantly greater. The solution to this problem lies only partly in providing more insulation on the thicker part. More heat must be put into the thicker part by the use of more turns of coils there (see 3.6).

3.4 Coils. An induction coil setup is shown schematically in Figure 5. The function of the coils is to carry the current whose magnetic field will induce a current in the pipe. Their electrical resistance should be low and their heat conductivity high. Copper is generally used for coils. The conductors may be in the form of bars or preformed clamps that are hinged and bolted together, hollow tubes through which water flows for cooling, or stranded cable. The hinged and bolted bars greatly reduce the cost of installing coils, but may cause problems at the connections because of overheating or arcing if they are not tightened properly. The hollow tubes required for water cooling are not as flexible as the standard cable which can be used where water cooling is not required. All coils must be wrapped in the same

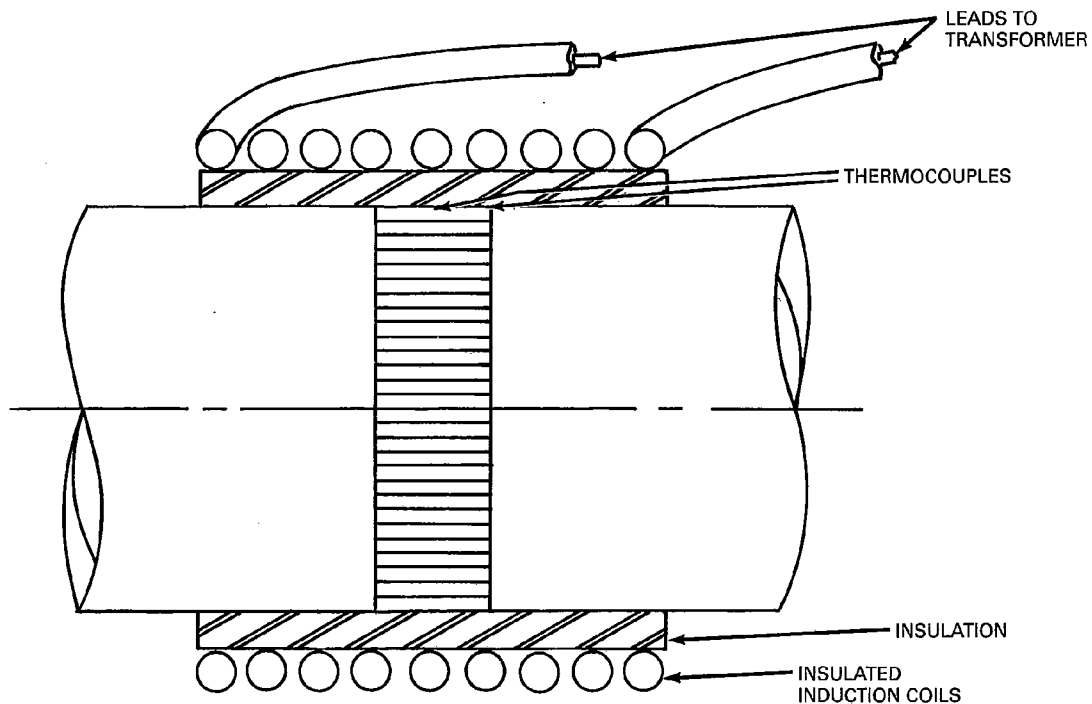


Figure 5 — Induction Coil Setup

direction around the pipe; otherwise, their magnetic fields will be at least partly in opposition to each other, and heating will be difficult, if not impossible.

3.5 Ampere Turns. The energy input to the pipe is approximately proportional to the ampere turns, which is the product of the current in the coils and the number of turns of the coil around the pipe. Both of these factors can be changed to regulate the energy input.

Current can be controlled effectively by changes in the taps on the transformer in 60-cycle units or by changing the output of the generator in 400 cycle motor-generator units. The upper limit of the current is determined by either the supply to the machine or the capacity of the machine. Current can also be controlled by either stopping or starting the flow of current or changing its frequency or amplitude, or both. Only newer machines have the solid state, phase balanced sources that permit varying frequency and amplitude.

The amplitude of the current and the number of turns in the coils directly affect the total heat input. Since only the current can be conveniently varied once the postweld heat treatment has been started, it is important to preplan these variables. If the applied frequency and voltage remain constant and the number of turns is decreased, the current in the coils will increase proportionately. However, for a given frequency and voltage, the number of turns can be varied within a relatively narrow range. If too few turns are used, the current will exceed the capacity of the machine. If too many turns are used, the system may have insufficient capacity to heat the pipe to the desired temperature.

3.6 Location of Turns of the Coil. Current is induced in the pipe only in the metal under the coils. The width of the heated band is thus determined by the width of the coils. Should a wider band be desired, the turns can be spaced farther apart by the use of insulation between them or by leaving a gap in between the coils at the center of the heated section. Such a gap can be left because heat is conducted into this region from the metal heated on either side. When induction coils are used for preheating a joint, a gap must be provided in the coils in order that there be access for the welder. Often, the coils can be left in this position for postheating, provided adequate insulation is used over the part of the pipe not covered with coils.

If coils are water cooled, they may safely be wound with several layers on top of each other. Stranded cables and solid bars may overheat if one layer covers another completely.

Cables and cable leads should not be coiled and should be as short as possible, because additional undesirable inductance will be produced, and parts within coiled cables and leads can be unintentionally heated.

Should the heat losses be greater in one direction than in another, such as in the case of a valve to pipe joint,

more turns should be used on the side that requires more heat input, for the energy distribution is in proportion to the ratio of the number of turns. This would mean having more turns on the thicker valve side. If the total number of turns is unchanged, a shift of only one or two turns will provide the needed change in temperature distribution.

For example, there might be six turns on the valve side and four on the pipe side. If the number of turns is increased, the extra ones are added to the side needing greater heat input. Note that adding turns will decrease the total energy input to the joint, unless the current to the coils is increased. This is true because the percentage decrease in the current is greater than the percentage increase in the number of turns, so that the product of amperes and turns, which is the measure of energy input, is decreased. It is a seeming paradox that increasing the number of turns decreases the total energy input, but warms up the side receiving the increased number of turns. In all such cases of unequal heat losses and input, it is advantageous to control the current to the two sides separately in order to balance the temperatures more closely.

3.7 Relative Advantages and Disadvantages of Induction Heating

3.7.1 The relative advantages of induction heating are the following:

- (1) High heating rates are possible.
- (2) Temperatures can be controlled within a narrow range.
- (3) Local hot spots can be avoided more easily.
- (4) The coils are relatively long-lived and less likely to fail during heating than some other equipment in the system.

3.7.2 The relative disadvantages of induction heating are the following:

- (1) The initial cost of the equipment can be higher than other appropriate heat sources.
- (2) The equipment is larger and less portable than many other systems.
- (3) It provides only limited means to compensate for nonuniform wall thickness and geometries and for the different energy requirements of the top and bottom of a pipe in the horizontal position.
- (4) If used for preheating, the power must be turned off during welding.
- (5) Extra set-up time may be required if many coils are needed.

3.8 Supplementary Information: Process Details. In this section, several process details are discussed which are intended to be helpful to an operator faced with the necessity of setting up an induction heating installation.

The example used assumes that the electric current is 60 Hz ac supplied by a transformer with taps on the

secondary. This does not imply that other equipment cannot be used.

3.8.1 Equipment and Materials. The following equipment and materials constitute what is considered to be the minimum recommended for an effective induction heating installation:

- (1) One transformer unit that has a secondary voltage of about 90 V.
- (2) Input cables from the power source to the input side of the transformer.
- (3) Cable leads from the transformer to the induction coils.
- (4) Induction coils long enough to encircle the pipe at least (12) twelve times and provide connections to the cable leads.
- (5) Thermocouples, chromel-alumel type K, located at the center of the weld and on each side of the weld at a distance equal to the wall thickness of the pipe.
- (6) Thermocouple extension leads, chromel-alumel type K or KX, to connect each thermocouple to the temperature measuring device.
- (7) A temperature recorder calibrated for chromel-alumel type K wire.
- (8) Suitable insulation, such as 2 in. (50 mm) thickness of mineral wool to fully encircle the pipe. The length of pipe to be insulated should not be less than 3 times the band to be heated.
- (9) Heat resistant twine (nonmetallic material) to tie the insulation into place. Typical materials include glass tape and ceramic fiber rope.

3.8.2 Thermocouple Attachment. Thermocouples should be attached to the pipe by methods described in 2.2.2.3 of this standard.

3.8.3 Insulation Attachment. The insulation attachment is discussed in 2.4.4. Special attention is called to the need to apply insulation directly to the pipe under the induction coils.

3.8.4 Induction Coil Attachment. When attaching the coils, all turns must be wound over the insulation without touching any metal. The winding shall be all in the same direction. Care should be taken while wrapping to assure that the insulation is not damaged and that the coils are neither too tight nor too loose. They should be properly spaced relative to the center of the weld so that the heated band is of the desired width and located to give an even temperature across the joint. Heat resistant twine is used to tie the coils down and prevent shifting during operation. Electrical insulating materials must be used to cover the connections between the coils and the cable leads and any joints within the coils.

3.8.5 Setup of Transformer. The transformer is connected to the power source with an input cable and to the coils with cable leads. The cables should be located so

that no one will trip over them and so that they are not coiled.

Good safety practices should always be followed. Whenever anyone is working on coils, and before the heating operation is about to begin, the main power switch should be in the open position and tagged "open". Safety barriers should be installed around the area of the joint.

4. Electric Resistance Heating

4.1 General. Resistance heating occurs when an electric current is passed through conductors with high electrical resistivity. By proper placement of the conductors and insulation, this heat can be directed to fulfill the requirement of preheating and post weld heating piping and tubing.

Manufacturers offer resistance heating equipment in a wide variety of sizes and shapes to fit practically any geometry. Most are quite flexible and able to conform closely to the shape to be heated, making them useful for shop or field use. The equipment required for resistance heating includes heating elements, insulation, power supply, and temperature-monitoring and controlling devices. A basic electric circuit for resistance heating is shown in Figure 6. The degree of sophistication in this process varies from manual operation with a single circuit to a fully automated operation with multiple circuits. Figure 6, which does not show any detailed control mechanism, has two circuits and permits the operator to equalize the temperature in the upper and lower pipe segments.

4.2 Heaters. All resistance heating devices consist of high resistance conductors and surrounding insulators, such as ceramic beads or ceramic fiber. The ceramic beads or fiber may be further protected by a braid of metal capable of resisting the high temperatures to which they will be exposed. The ends of the conductors are fitted with lugs or similar devices to facilitate connection to the power circuit.

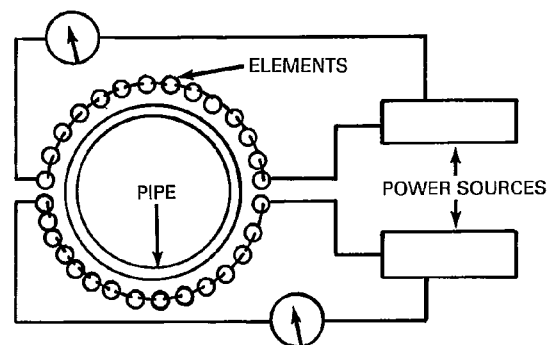


Figure 6 — Split Elements for Horizontal Pipe

The basic configurations for resistance heating devices are finger elements, preformed pads, and the single strand. Since each has a limited current-carrying capacity, the current should be monitored by a clamp-on ammeter. The number of heaters required is governed by (1) the mass to be heated, (2) geometry of the area to be heated, (3) the rate of heating and holding temperature, and (4) the power rating of the individual heaters.

For any type of resistance heater, the following precautions are applicable:

(1) For parallel hookups, heaters with the same resistance are normally used, otherwise, compensating resistors may have to be added to the circuits. If newer elements are combined with older ones, whose resistance may be changed because of oxidation during use, the overall resistance of a unit should be checked before a hook-up is made.

(2) A clamp-on ammeter may be used to check that the current supplied does not exceed the rating of the heaters.

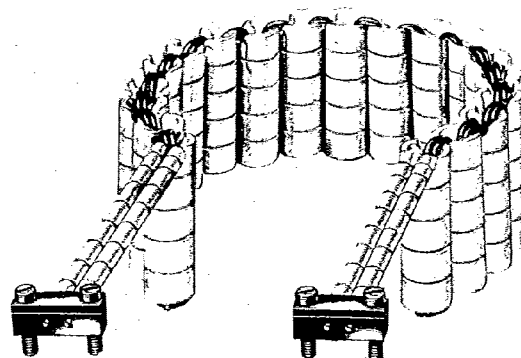
(3) All power should be turned off before heaters are connected to the power supply. This will provide for personnel safety and can prevent damage to the heater elements.

4.2.1 Finger Element Heaters. Finger element heaters, illustrated in Figure 7, are designed to fit around an entire pipe circumference or segments of a circumference. The ceramic sleeves electrically insulate the elements from each other and from the pipe. Finger element heaters are rated mainly by current capacity, with a typical limitation of 120 A. A fairly large number of fingers can be used in series because of the low voltage drop across each element. If the number of elements to be used requires more power than the power supply is capable of producing, additional power supplies (such as welding machines) may be required.

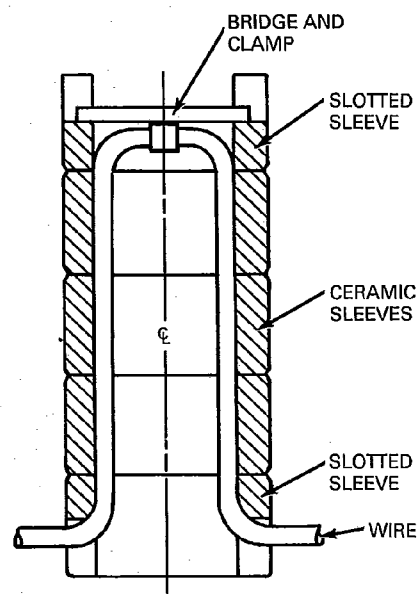
4.2.2 Braided Heaters. Braided heaters consist of a stranded inner core of fine gage, flexible nichrome resistance wires which are insulated with woven layers of silica fiber and heat-resistant wire. This insulated inner core is laid out in mat form and interlaced with wire to form a mesh-type heating pad, as shown in Figure 8.

Braided heaters can be attached directly to the pipe with stainless steel bands and covered with insulation, or they can be placed into special wire mesh pockets in fiber mesh heating blankets, which makes it possible to attach the heaters and insulation to the pipe at one time. Braided heaters can be positioned either longitudinally or circumferentially around the pipe.

4.2.3 Flexible Ceramic Pad (FCP). The FCP consists of a nichrome metal ribbon or wire which is embedded and arranged into ceramic beads to form a pad. They are installed in much the same way as braided heaters. Multiple heaters can be attached to provide zone heating control as shown in Figure 9.



(A)



(B)

Figure 7 — Finger Element Heater

4.2.4 Wrap-Around Heaters. A typical wrap-around heater consists of a nichrome wire element embedded in a 1 in. (25 mm) thick ceramic fiber blanket which is housed by a stainless steel shell. A photograph and diagram of such a wrap-around heater are shown in Figure 10.

The heater is curved to fit snugly around a given size pipe. This means that each different size of pipe to be heated will require a different size wrap-around heater. The preshaped body of the wrap-around makes it easier and faster to set up in the field. However, its rigid body design and relatively high cost limit its use to repetitive heat treatments in straight-run pipe of the same size.

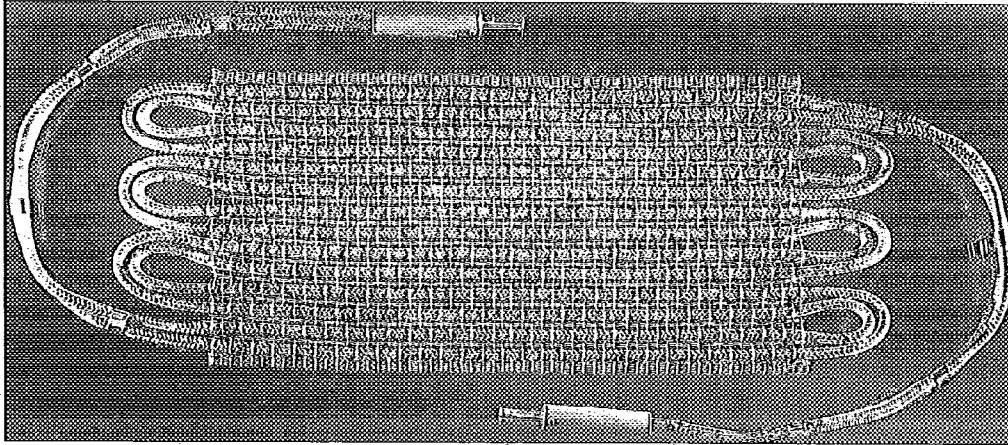


Figure 8 — Braided Heater

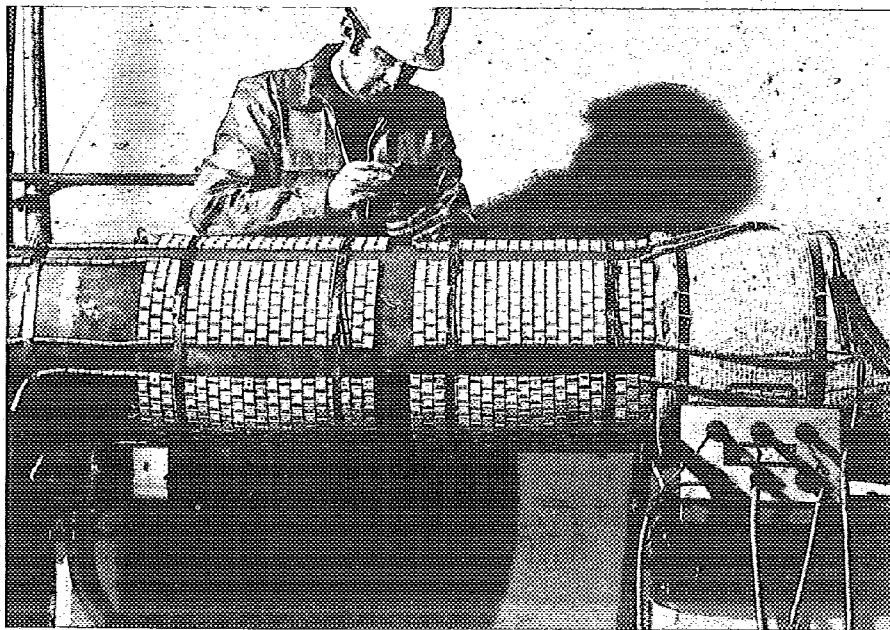


Figure 9 — Typical Setup of Flexible Ceramic Pad Elements

4.2.5 Single Strand (Rope Type). Single strand heaters are of similar construction as braided heaters. They are available with silicon fiber insulation, and with ceramic insulation beads similar to the Flexible Ceramic Pad (see 4.2.3).

Single strand heaters can be wrapped around a pipe in much the same way as induction coils. They can also be formed into pads, including irregular shapes, to fit around and between nozzles and to compensate for unequal metal thicknesses.

4.2.6 Heater Attachment. The method of attachment of the heaters depends on the type used. Whenever the axis of the pipe is in a horizontal position, the heater should be attached so that the center of the heater is at the bottom and the two ends are near the top. This should result in a small gap near the top of the pipe.

Once in place around the pipe, the heater can be secured with a stainless steel strap or other suitable connector. Carbon steel bands tend to sag at normal postheat treatment temperatures, allowing the heaters to

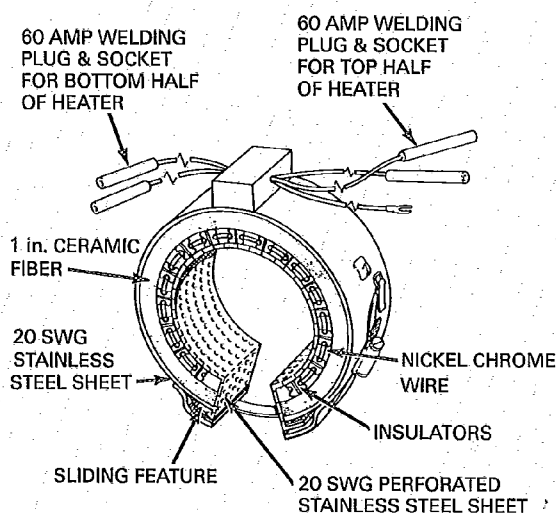
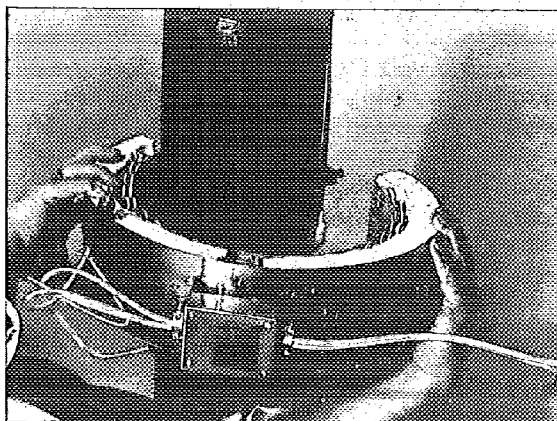


Figure 10 — Wrap-around Heater

slide and overlap. The heater is then ready to be insulated and connected to the power supply.

If braided heater blankets are used, a check should be made to insure that the blanket is in place around the pipe. None of the heaters should overlap the insulation, since this could damage the heater. Once good fit is assured, the blankets can be secured to the pipe with stainless steel straps. Then insulation should be wrapped around the blanket and secured with wire. The heaters are then ready to be connected to the power supply.

Figure 11 illustrates the attachment of various types of heaters.

4.3 Insulation. Application of insulation is thoroughly discussed in 2.4.

4.4 Power Sources. Electric power needed for resistance heating can be provided by many sources, ranging from engine driven welding machines to normal commercial power lines. Either AC or DC equipment can be used. The selection of the system for any given application depends upon availability, portability, cost effectiveness, and type of heaters and controllers. In general, different equipment is required if the power source is welding generators than if the power source is 220/440 volt commercial lines, and most of the heating equipment is not interchangeable with such diversified types of power source.

To judge the adequacy of a power system, the total power requirement should be established. This can be achieved by applying the following formula:

$$kW = \frac{M \times c \times R}{3412 \times E}$$

or in metric (SI) units

$$kW = \frac{M \times c \times R}{3600 \times E}$$

where:

kW = power in kilowatts

M = mass of metal to be heated (in pounds or in kilograms)

c = specific heat (in BTU/lb/°F or in kJ/kg/°C)

R = maximum rate of heating (in °F/hour or in °C/hour)

E = insulation efficiency (use 0.4 for well insulated assemblies)

3412 BTU = 1 kilowatt hour

3600 kJ = 1 kilowatt hour

Note: Specific heat varies with temperature. Use 0.20 BTU/lb/°F or 0.83 kJ/kg/°C for steel

If insufficient power is available, it may be possible to successfully achieve postheating by reducing the rate of heating.

When selecting welding machines as power sources, it is important to recognize that most welding machines are rated at a duty cycle of less than 100%. For manual and semiautomatic pipe welding, which requires many starts and stops, there is no need to select equipment with a 100% duty cycle. However, when used for heating, the equipment may be continuously on line for many hours. Therefore, to prevent overloading or damaging the equipment, it is important to determine and not to exceed the current at its 100% duty cycle rating.

The cables should not be any longer than necessary, and they should not be coiled, since both conditions reduce the availability of useful power. It is also very important that cables be used as leads to and from the power source rather than using steel structures as conductors. All connections should be checked for tightness

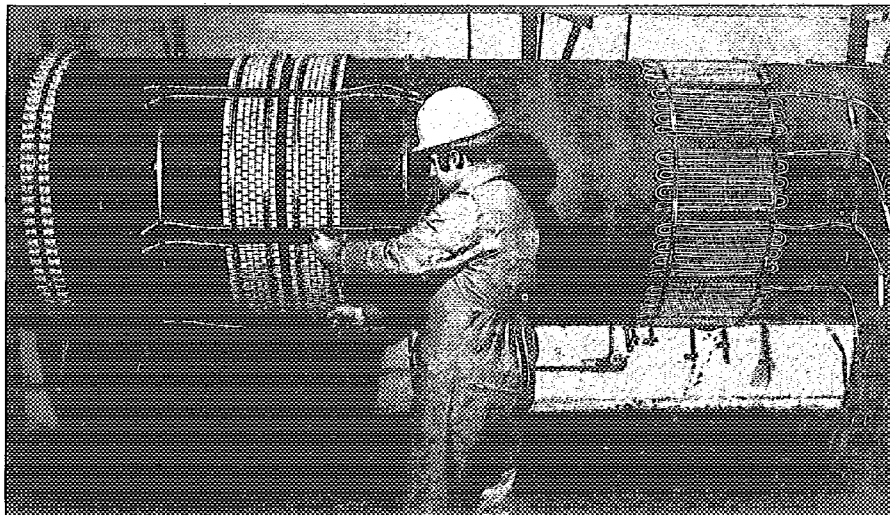


Figure 11 — Attachment of Various Types of Heaters

and should be supported to reduce the strain on the heating elements.

4.5 Temperature Monitoring and Controlling Devices. These subjects are discussed in detail in 2.2.

4.6 Relative Advantages and Disadvantages of Resistance Heating. The relative advantages of resistance heating for local heat treatment of welds are as follows:

(1) Continuous and even heat can be maintained throughout the welding operation and during long breaks.

(2) Temperature can be adjusted accurately and quickly.

(3) Welders can work in relative comfort and do not have to stop intermittently to raise preheat temperature.

(4) Uneven heat input can be obtained easily, such as may be required for the top and bottom halves of a pipe or where pipes are attached to heavier sections such as valves.

The relative disadvantages are as follows:

(1) Elements may burn out during a heat treatment.

(2) It is possible for a resistance element to short itself out to the pipe, producing arcing spots.

4.7 Supplementary Information: Process Details. The following suggested procedure is intended to be helpful to an operator faced with the necessity of setting up a resistance heating installation.

4.7.1 Thermocouple Attachment. See 2.2.2.3 for details.

4.7.2 Heater Attachment. See 4.2 for details.

4.7.3 Insulation Attachment. See 2.4.4 for details

4.7.4 Power Source. See 4.4. With the power supply in the off position, the leads should be connected. Cable lengths should not be any longer than necessary and should not be coiled. All connections should be checked for tightness, and they should be tied off at both ends to take the strain off the heaters.

4.7.5 Startup and Operation. The recording chart should be turned on. All dial selector knobs must be in the off or minimum output position before starting the power supply. This action will guard against an overloading or surging, which could burn out or severely damage the heating elements. A clamp-on ammeter should be placed around one of the cables and the power supply activated. The amperage should not exceed the heating element rating. The current should be gradually increased. When the holding temperature is reached, the current should be reduced to maintain this temperature.

At the completion of the holding period, only enough current should be supplied to the heaters to keep the rate of cooling below the maximum specified. In some cases, the current can be shut off completely. The temperature recorder should be left running until the temperature reaches the minimum required by the procedure. At this time, the pipe and joint number should be marked on the temperature chart and the chart filed with inspection records, if required.

5. Flame Heating

5.1 General. In local heat treating of welds with one or more flames (torches), the heating operation is much more of an art than a science. The amount of heat and

concentration of heat transferred to the weldment depends not only on the amount of fuel consumed and on the completeness of combustion, but on the adjustment of the flame, the distance between the flame and the weldment, the manipulation of the flame, and the control of heat losses to the atmosphere. In view of the above, other heating methods are preferred.

Flame heating has been successfully used for work on relatively small pipe sizes. It is a method which should be applied with care and only by an operator who is experienced or is under close supervision by an experienced operator. Weldments can be severely damaged by improperly applied flame heating.

5.2 Heat Sources. Heat for flame heating is produced by burning a fuel gas mixed with air or oxygen. If the weldments are of considerable mass, or if the work is to be done fairly quickly, these gases should be burned with oxygen rather than air.

When air is used, the volume should be large enough to produce nearly complete combustion. The air may be forced into the fuel stream under pressure or, sometimes, simply aspirated into the flame.

5.3 Torch Sizes. The torch size should be as large as is practical and convenient for the job. The larger size tips and flames not only produce more heat more quickly, but tend to distribute it more evenly. The use of cutting torches should be avoided since they increase the risk of burning or cutting the metal.

5.4 Heated Area. In order to get a good, even heat in the full heat-affected zone, the area of postheating should extend at least 2-1/2 T on each side of the weld (see 2.3.1). One should be wary of overheating local areas. The thicker the pipe wall, the more important it is to allow sufficient time for heat to diffuse through it, and it may also be advisable to apply heat to the internal surface of heavy wall pipe. It follows that it is also important when using flame heating to measure the temperature carefully and in enough regions to assure that thermal gradients are not excessive.

5.5 Flame Adjustment. Neutral or slightly reducing flames should be used; an oxidizing flame should not be used.

5.6 Flame Attitude. The flames should be kept close enough to the pipe to get maximum heat transfer and to get the shielding effect of the flame's outer area, but not close enough to get any melting effect. The sharp, pointed, inner cones of the flames should never touch the pipe.

The flame or flames around the pipe should be manipulated so as to distribute the heat as evenly as possible. Uneven heat distribution will cause distortion, warpage, and residual stress.

On larger sizes of pipe, more than one torch should be used. This will help to distribute the heat. When more

than one operator is working on the heating operation, it should be planned in advance what each one will do.

5.7 Protection from the Elements. The pipe to be heat-treated must be well protected from moisture and wind.

5.8 Holding. When the weld area has been brought to the proper temperature, it can be held at that temperature with lower heat input by continuing to manipulate the torches around the pipe or by holding them at some greater distance from the pipe.

5.9 Cooling. When the weld area has been brought to the proper temperature and held there for the correct length of time, it should be covered with insulation to allow slow cooling.

5.10 Relative Advantages and Disadvantages of Flame Heating

5.10.1 The relative advantages of flame heating for local heat treatment of welds are low cost and portability.

5.10.2 The relative disadvantages of flame heating for local treatment of welds are the following:

- (1) Minimal precision and repeatability
- (2) Minimal uniform temperature distribution
- (3) The great amount of operator skill it requires

6. Exothermic Heating

6.1 General. Most local heat treatments of welds employ a heat source which can be monitored to obtain the desired heat treating cycle. They employ coils, wires, flames, and other heating media that can be reused for several, and at times unlimited, applications, but require the attention of an operator. The exothermic system, shown in Figure 12, employs a heating source that is completely consumed, but does not require a labor force beyond the initial installation, which usually takes less than one or two man-hours.

Since the late fifties, exothermic materials have been marketed to perform this chemical heating method for welding, and extensive field experience has been obtained

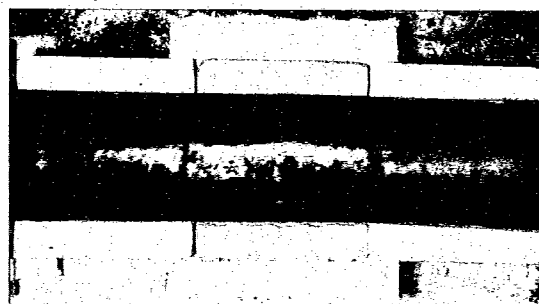
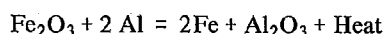


Figure 12 — Application of Exothermic Kit

with regard to this process by construction and maintenance organizations.

Some facilities desire the presence of a watchman during the burning phases of the exothermic heat treatment, but this person has no control over the process. Thus, the engineer should plan the operation in detail prior to ordering and employing any exothermic materials.

6.2 Nature of the Process. Every exothermic process involves a chemical reaction between materials that release heat. One such process uses iron oxide and aluminum, and the reaction can be expressed by the following equation:



The temperature produced, about 5000° F (2760° C), is too high for normal heat treatment of welds; therefore, insulation is placed between the exothermic materials and the pipe to be heated.

The chemical composition of the exothermic heat treating material for welds is proprietary. The heat treating cycle is controlled by a combination of the total heat content, the size and shape of the exothermic mass, and the size and shape of the insulation. Once the heat treatment has been started by the ignition of the exothermic mass, it is impossible to perform any adjustments. Other heat treatment processes can be modified as the operation progresses, but exothermic heat treatment must be completely planned in advance to be successful.

The exothermic process produces some smoke during the burning phase which usually lasts less than 30 minutes. In accordance with manufacturers instructions, exposure to these fumes should be limited. This usually presents no problem for the persons performing the heat treating, since they do not have to be in close proximity to the work area. However, care should be taken that no workers are in confined areas above the PWHT location.

Failure to understand these principles has caused problems when using exothermic materials. Most mistakes result in the failure of the weldment to reach the desired holding time and temperature. Such shortened heat treatment may result in excessive hardness, lack of ductility or loss of corrosion resistance. Typical mistakes that have resulted in unsatisfactory exothermic heat treatment include the following:

- (1) Undersize exothermic mass caused by:
 - (a) Specifying a lower holding temperature than desired
 - (b) Using heavier base metal wall thickness than initially scheduled
 - (c) Ordering or designing an exothermic package to nominal pipe wall and using pipe with minimum wall thickness
- (2) Damaged exothermic material due to:
 - (a) Breakage in transport and handling

(b) Exposure to excessive moisture any time between manufacturing and application

(3) Inadequate insulation such as:

(a) Failure to employ the full amount specified for a specific joint, whether adjacent to or around the exothermic material

(b) Damage or loss of insulation or substitution of lower grades

(c) Improper installation (excessive spaces or gaps)

(4) Environmental cooling including:

(a) Liquids inside the component to be heat-treated

(b) Air currents (the chimney effect) inside component

(c) Extreme low ambient temperature or very high wind velocities

(5) Workmanship problems, such as:

(a) Improper installation of exothermic and insulation materials (excessive spaces or gaps)

(b) Failure to ignite all of the "light up points"

Attention to all the details in this section will help produce a successful exothermic heat treatment.

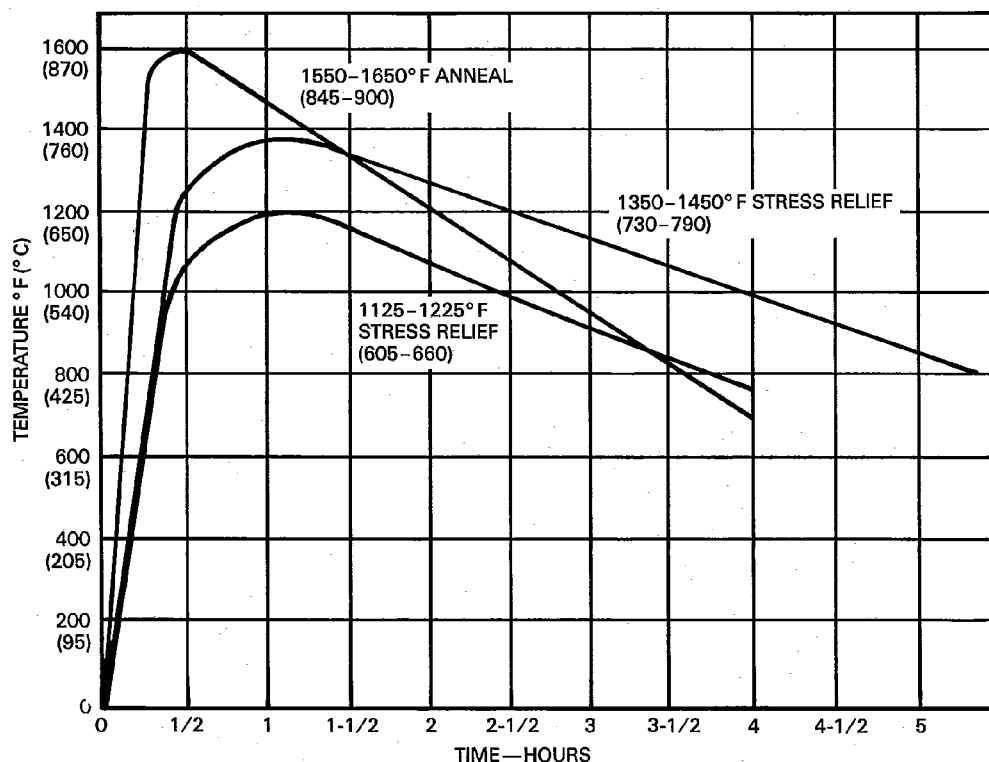
6.3 Selection of the Exothermic Package. Having reviewed the nature of the process and its problem areas, a plan should be employed to determine whether the exothermic process is suitable for a specific application. The following essential variables should be considered in answering this question and selecting an exothermic system.

6.3.1 Desired Rate of Heating. As soon as the exothermic material is ignited, heat is produced at a rapid and uniform rate over the entire area covered by the heat treating kit. For wall thickness up to about 1-1/2 in. (40 mm), this heat will equalize rapidly through the full thickness whenever the material is properly installed and ignited. The operator can do nothing to change this rate of heating.

There appears to be some difference of opinion regarding the desired rate of heating. Some codes and specifications establish no limits as long as the heating rate is uniform. Others impose maximum rates expressed in degrees per hour per unit of thickness. Depending upon code jurisdiction and customer requirements, each user should determine whether the heating rate is or is not to be restricted for a specific heat treatment. For codes and specifications which impose maximum heating rates, an exothermic heating system is not acceptable.

6.3.2 Desired Holding Temperature. The chemical composition or grade of the base and weld metal should determine the optimum heat treatment temperature and the acceptable tolerances. While it may not be possible to satisfy every possibility, suppliers may be able to supply special heat treating packages. At present, three basic heat treatments are commercially available (Figure 13).

(1) 1250° F (675° C) maximum temperature with a one hour holding time above 1100° F (595° C) for each



Note: Heating and Cooling Cycles are Reproducible Within $\pm 20^\circ\text{F}$ (11°C).

Figure 13 — Typical Exothermic Heat Treatments with NPS 6 Sch. 80 (168 mm OD $\times$ 11 mm wall) Pipe Heating and Cooling Cycles

in. (25 mm) of wall thickness. The minimum holding time is 30 minutes. This meets most carbon steel heat treatment requirements.

(2) 1450°F (790°C) maximum temperature with a one hour holding time above 1300°F (705°C) for each in. (25 mm) of wall thickness. The minimum holding time is 60 minutes. This meets most low alloy chromium-molybdenum steel heat treatment requirements.

(3) 1650°F (900°C) maximum temperature with a cooling rate of about 300°F (165°C) per hour from 1500 to 1000°F (815 to 540°C) where reduction in hardness of one to three percent chromium-molybdenum steel is the primary objective of the heat treatment. The higher temperature packages can produce lower material costs and reduce sensitivity to installation errors, but are not recommended for five to nine percent chromium-molybdenum steels which require extra slow cooling rates.

6.3.3 Desired Holding Time. The holding time discussed in conjunction with hold temperature and illustrated in Figure 13 cannot be drastically changed. Thus, if metallurgical considerations require a different hold-

ing time (such as for an aging treatment) the exothermic system should not be selected.

6.3.4 Cooling Rate. While it is possible to adjust the cooling rate slightly beyond the examples shown in Figure 13 by changing exothermic mass and insulation, extreme modifications are not possible. Thus, the exothermic system should not be used if cooling rates of less than 200°F (100°C) per hour have been specified. In addition, it is impossible to use the exothermic system for a two-step cooling procedure required for some alloys, i.e., slow cooling to 1000°F (540°C), followed by rapid cooling to 600°F (315°C).

6.3.5 Wall Thickness and Pipe Diameter. Since the mass of the exothermic system must be designed for the mass of steel to be heated, the wall thickness of the pipe must be carefully determined before establishing the heat treatment requirements.

The actual wall thickness must be employed for the design of the exothermic kit; for example, an exothermic system designed for Sch. 40 pipe will not adequately heat treat a Sch. 80 assembly.

6.3.6 Joint Geometry. The type of joint subject to heat treatment determines the amount of metal to be heated. A butt weld involving a weld-neck flange includes more mass than the joining of two pieces of pipe. If an elbow is used, the amount of metal may not increase, but the method of attachment may differ; however, both butt joints can be heated at once.

Special systems can be designed to heat treat several return bend joints at one time if they are in close proximity. For nozzles and coupling attachments, a completely different joint geometry must be heated, and a specific exothermic package must be designed or selected.

6.4 Premolded Exothermic Kits. Prior to 1970, all exothermic systems were designed by the suppliers for specific applications. The necessary components were designed and assembled in a kit for one job, such as an NPS 8 Sch. 80 (220 mm OD $\times$ 13 mm wall) butt weld. Figure 14 illustrates a kit which contains the premolded exothermic mass with attached high-temperature insulation, some low-temperature insulation such as mineral wool, insulation cement, and wire to assemble the kit. This minimizes field assembly time but requires maximum preplanning by the erector or the maintenance engineer.

As indicated earlier, any change in material, size, or wall thickness might make the original kit unsuitable or ineffective for the job. For new construction or major repair activities that involve detailed and advanced planning, the prepackaged kit often represents the most economical application of exothermic materials.

6.5 "Do-It-Yourself" Kits. Since 1970, "Do-It-Yourself" exothermic kits have been available (Figure 15). The supplier provides the user with flexible sheets of exothermic materials, insulation, and instruction sheets based on desired heat treatment cycles, material wall

thicknesses, and joint geometries. This enables the maintenance personnel to build their own exothermic kit to heat treat any joint for which they have or can obtain an instruction sheet. They do not have to wait for the shipment of a specific kit from their supplier.

Instruction sheets for the selection and installation of these do-it-yourself flexible exothermic materials have been developed for many piping combinations. Typical data for pipe-to-pipe and pipe-to-elbow butt joints are shown in Figures 16 and 17. Since the amounts of exothermic material and the thickness of the insulation have

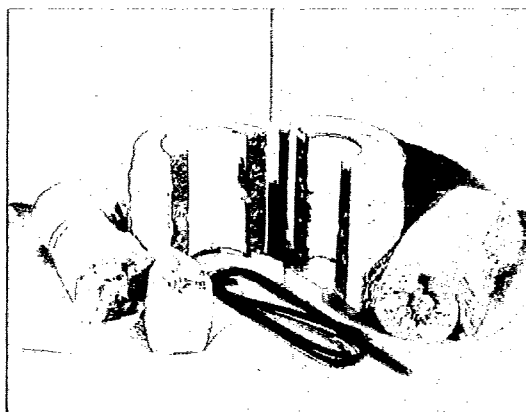
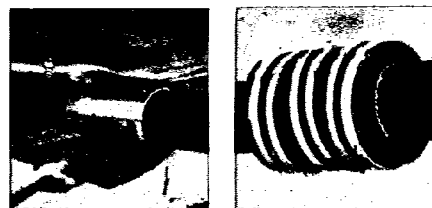


Figure 14 — Components of Premolded Exothermic Kits



(A)

(B)

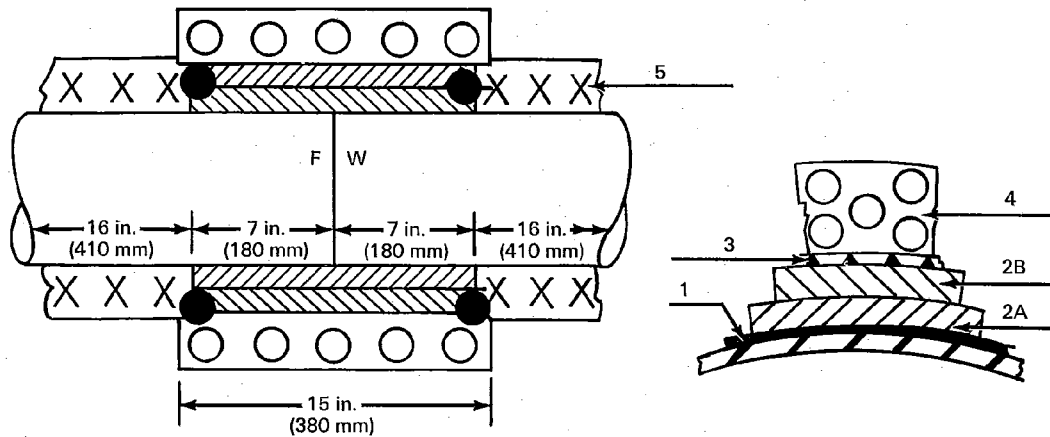


(C)



(D)

Figure 15 — Application of Flexible Exothermic Kit



● LIGHT UP POINTS

ITEM NO.	CODE	DESCRIPTION	WIDTH in. mm	LENGTH in. mm	NO. PCS. REQ'D.
1		INSULATION 0.062 in. (1.57 mm) THICK RED ENDS	14 360	29-3/4 760	1
2A		EXOTHERMIC CHARGE (FAC)	14 360	18-1/4 460	1
2B		EXOTHERMIC CHARGE (FAC)	14 360	23-1/2 600	1
2C		EXOTHERMIC CHARGE (FAC)			0
2D		EXOTHERMIC CHARGE (FAC)			0
3		0.250 in. (6.35 mm) THICK X 2 in. (50 mm) INSULATING STRIPS	2 50	29 740	4
4		COMPOSITE INSULATION	15 380	36 910	1
5		LOW TEMPERATURE BLANKET	16 410	21 530	2
5A		LOW TEMPERATURE BLANKET			

Figure 16 — Materials for the Exothermic Heat Treatment of NPS 4 Sch. 80 (115 mm OD x 9 mm wall) Pipe-to-Pipe Butt Joints at 1300-1450°F (705-790°C)

been tailored to a specific application, it is essential that a data sheet be selected on the basis of pipe diameter, wall thickness, type of joint, and desired heat treating temperature.

The final selection between the premolded and the Do-It-Yourself kits depends upon geographic location, type of heat treating activity, labor costs, and type or size of joint. While the material cost of the premolded kit is higher, it requires less labor for installation at the site. A flexible kit, together with a complete instruction data book, permits the engineer to adapt the material to emergency heat treatments.

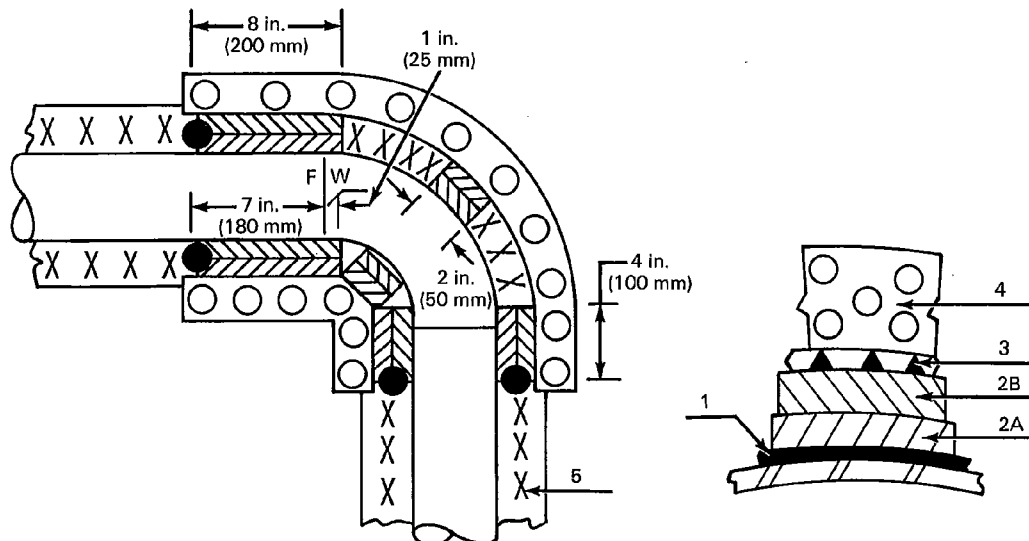
6.6 Relative Advantages and Disadvantages of Exothermic Heating

6.6.1 The relative advantages of exothermic heating for local heat treatment of welds are the following:

- (1) No capital equipment cost.
- (2) An operator may not be required during heat treating.
- (3) Maximum portability.

6.6.2 The relative disadvantages are the following:

- (1) Not applicable to preheating.



● LIGHT UP POINTS

ITEM NO.	CODE	DESCRIPTION	WIDTH in. mm	LENGTH in. mm	NO. PCS. REQ'D.
1		INSULATION 0.062 in. (1.57 mm) THICK RED ENDS	2 50 4 100 8 200	29-3/4 760	1
2A		EXOTHERMIC CHARGE (FAC)	2 50 4 100 8 200	18-1/4 460	1
2B		EXOTHERMIC CHARGE (FAC)	2 50 4 100 8 200	23-1/2 600	1
2C		EXOTHERMIC CHARGE (FAC)			0
2D		EXOTHERMIC CHARGE (FAC)			0
3		0.250 in. (6.35 mm) THICK X 2 in. (50 mm) INSULATING STRIPS	2 50	29 740	4
4		COMPOSITE INSULATION	36 910	36 910	1
5		LOW TEMPERATURE BLANKET	16 410	21 530	2
5A		LOW TEMPERATURE BLANKET			

Figure 17 — Materials for the Exothermic Heat Treatment of NPS 4 Sch. 80 (115 mm OD x 9 mm wall) Pipe-to-90° Elbow Butt Joints at 1300-1450°F (705-790°C)

(2) No adjustment possible once heat treatment is initiated.

(3) Limited flexibility for meeting some code and engineering requirements for heating rate, holding time, and cooling rate.

(4) Limited availability of exothermic systems.

7. Gas-Flame Generated Infrared Heating

7.1 General. Two of the heating methods described in this document rely upon radiation as the principle mechanism for transferring heat from the source to the work.

In one of the two methods, gas is burned with air in a specially designed burner which then radiates the energy to the work. This process, described in this section, is just now beginning to find application for preheating or postheating of welds. The other radiant method, described in section 8, Radiant Heating by Quartz Lamps, utilizes electrical quartz lamps as the heat source.

7.2 Fundamentals. Infrared radiation is generated by all hot bodies and is electromagnetic in character, just as are light and radio waves. Some of the wavelengths are more effective in actual heating than others, and 2.0–6.0 μm appears to be the most effective range (see Figure 18).

Since infrared energy behaves just as light does, its intensity falls off as the square of the distance between the emitter and the receiver. Also, for any energy falling onto a body to be heated, part is absorbed, part is transmitted, and part is reflected.

Any surface modification to metals such as polish, scale, rust, and so forth, varies the reflectivity and, therefore, the absorption.

Finally, since the process is one of radiation transmission, the area of the receiver which "sees" the transmitter should be as effectively disposed as possible, and losses due to stray radiation should be kept to a minimum.

7.3 Burner Arrangements. Gas-flame generated infrared burners which have been successfully used in practice are shown in Figures 19 and 20. Figure 19 shows a number of flat-faced burners arranged to secure uniform heating of the required part contour. Figure 20 shows burners shaped to the contour of the part to be heated.

7.4 Controlling Gas-Flame Generated Infrared Energy. One of the significant virtues of gas-flame generated infrared energy is its ease of control and application. Because of the electromagnetic nature of the heat, it is

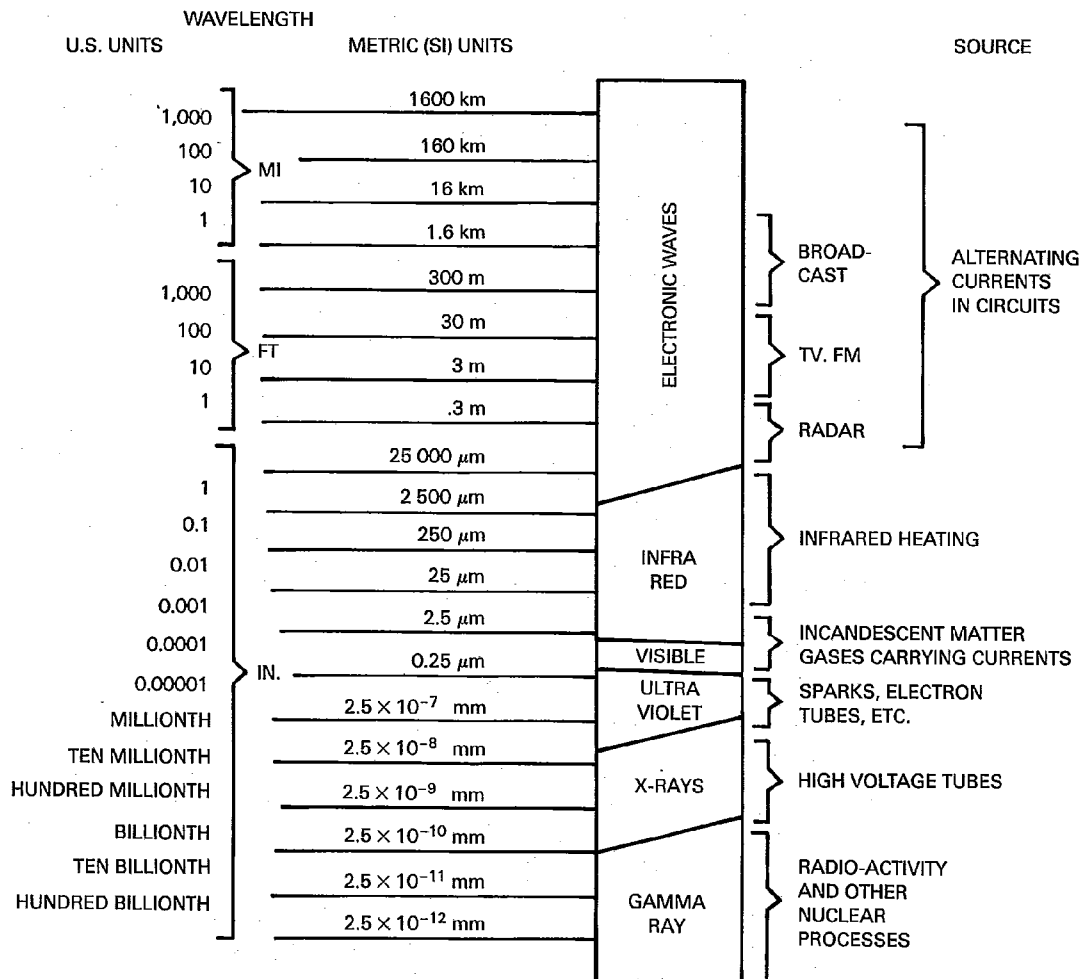


Figure 18 — Electromagnetic Spectrum

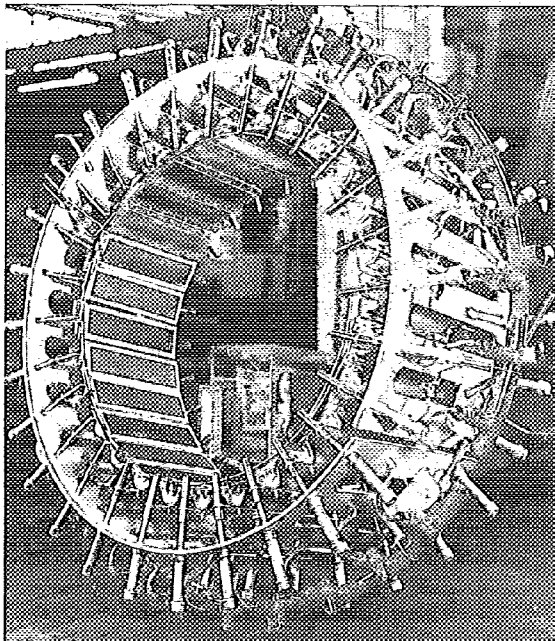


Figure 19 — Gas-Flame Generated Heating Unit for 14 ft. (4.9 m) Diameter Circular Weld Joining a 4 in. (100 mm) and a 3 in. (76 mm) Thick Section

transmitted from the source to the pipe surface instantaneously. Since the heat transmitted is determined only by the distance between the heat source and the part being heated, and by the volume of fuel generating the heat, and since the distance is generally constant for a given application, the only control is that of regulating the gas flow. Controllers for automatic regulation are available.

7.5 Relative Advantages and Disadvantages of Gas-Flame Generated Infrared Heating

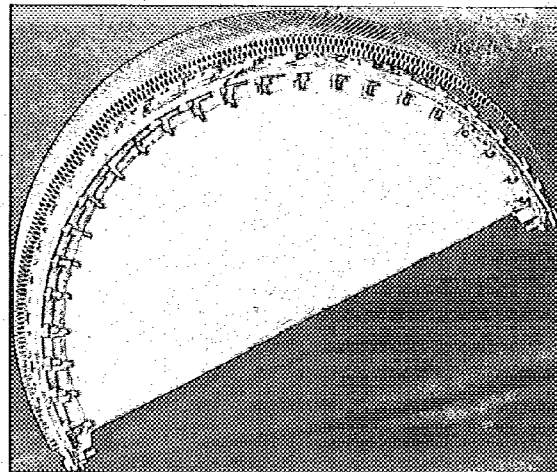
7.5.1 The following are advantages of gas-flame generated infrared heating for preheat, interpass, or post-heat treatment of welds:

- (1) Use of relatively economical fuel
- (2) Availability of suitable control equipment
- (3) No insulation is used in the area to be heated

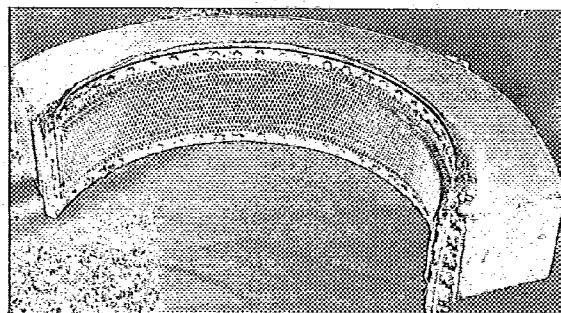
7.5.2 A relative disadvantage of gas-flame generated infrared heating for preheat, interpass, or postheat treatment of welds is that separate "furnaces" must either be fabricated or available for each pipe diameter.

8. Radiant Heating by Quartz Lamps

8.1 General. Quartz lamps can be used for both post weld heat treatment and preheating. This method can



(A) BURNER FOR INTERNAL SURFACE



(B) BURNER FOR EXTERNAL SURFACE

Figure 20 — Burners for Circumferential Welds

provide for accurate control of time and temperature.

The quartz lamp heating elements are usually located outside the pipe itself. The heat is radiated to the outside surface of the pipe and is conducted through the pipe wall to the inside. Power requirement calculations are quite similar to those for resistance heating; capability for increased speed of heating will alter those calculations in the direction of less heat loss because of higher heating rates. Like resistance heating and conventional furnace heating, thermocouple temperature measurements are required to actuate a feedback control system.

The process is clean in the sense that no products of combustion are available to react with or contaminate the surface. There is no odor, and little waste heat, and thus, no need for forced ventilation of the working area to achieve operator comfort.

8.2 Description of the Heating Method. Radiant heating by quartz lamps is a process which uses electric current to heat a tungsten electrode to a temperature high enough to emit infrared waves. This temperature is in the range from 4000° to 5400° F (2200° to 3000° C).

The quartz lamp device is designed to encapsulate the tungsten wire with argon in an envelope of quartz. The filament electrical characteristics are such that voltages of 120, 240 or 480 V can be applied. Lamps range in length from 2–38 in. (50–970 mm), with the most frequent lengths, for purposes of local pipe stress relief, being in the range of 5–10 in. (130 to 250 mm). Thus, a 10 in. (250 mm) lamp might have a voltage of 240 V, 24 V per in. (0.94 V per mm) and be conducting a filament current of four to eight amperes. This gives an input power density of 0.1 to 0.2 kW/in. (3.9 to 7.9 W/mm) of lamp. The lamps can also be used at twice “rated” voltage at lower duty cycles, for higher temperature applications. This gives approximately 2.7 times rated power output. However, the lower power level is adequate for most stress relief applications and will give appreciably longer lamp life. Such a lamp is shown in Figure 21. The quartz tube passes the infrared radiation with an efficiency of approximately 86 percent.

A second important part of the apparatus is the reflector, which redirects the heat which is radiated in all directions, focusing it toward the work. Infrared radiation is not converted to heat until it strikes an absorbing surface. Metallic reflectors are chosen to be reflective rather than absorbent.

Thus, the heat which starts in the wrong direction is channeled properly, as indicated in Figure 22, and strikes the work material. The process is aided if the work material is not too reflective. That is, the reflector should reflect or reradiate; the work should absorb. Ceramic reflectors depend on reflection plus reradiation; their lower reflectivity causes a temperature increase, but low thermal conductivity keeps the surface temperature high so that the energy is directed back toward the workpiece by reradiation.

The usual alignment of equipment for heating of a pipe would be to arrange a sufficient number of these filament-reflector units around the circumference of the pipe, with filaments running parallel to the pipe axis, so that side by side reflectors approximately 1 to 2 in. (25–50 mm) away from the pipe outer surface completely fill that circle. This is indicated in Figure 23.

The third fundamental element of the system is temperature sensing and feedback control. Quartz lamp radiant heaters have the potential for very rapid heating and cooling. Without careful sensing and control, steep thermal gradients and detrimental overheating can be experienced. Thus, properly installed and protected thermocouples and programmed time-temperature devices are desired for overall control. Life of the devices depends to a great extent on protecting them from overheating.

Reflectors, quartz lamps themselves, and the “end seals,” that is, the electrical connections to the lamps at either end, are all sensitive to overheating. This requires proper selection of the cooling medium and design of the overall device for cooling.

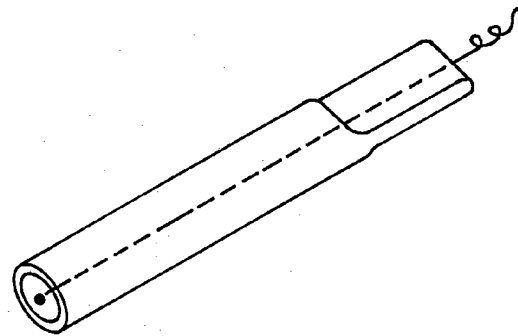


Figure 21 — Quartz Tube; Argon and Tungsten Filament

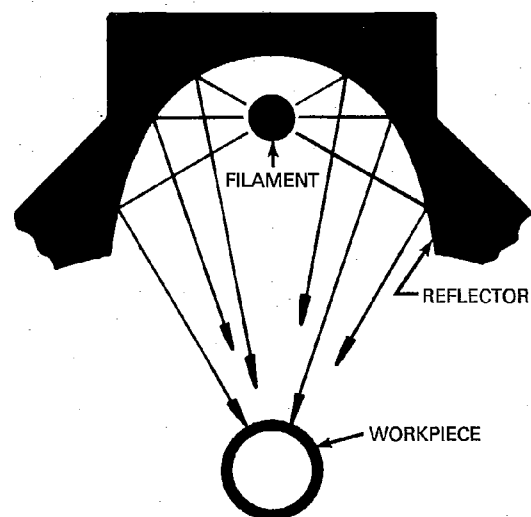


Figure 22 — Relative Positions of Filament, Reflector, and Work

8.3 Radiant Heating Equipment

8.3.1 Quartz Lamps. Table 2 describes length, electrical characteristics and power output, for the lamps used for preheating or postheating. Suppliers should be consulted prior to final selection of lamps for specific applications. Quartz lamps come in two basic designs: the straightforward tungsten filament and the iodine cycle lamp. The latter, as noted in the table, has a higher power output per length of lamp and is used primarily for more concentrated heating tasks than those of concern in this document. If the end seals experience temperatures greater than 650° F (345° C), high temperature seals should be specified.

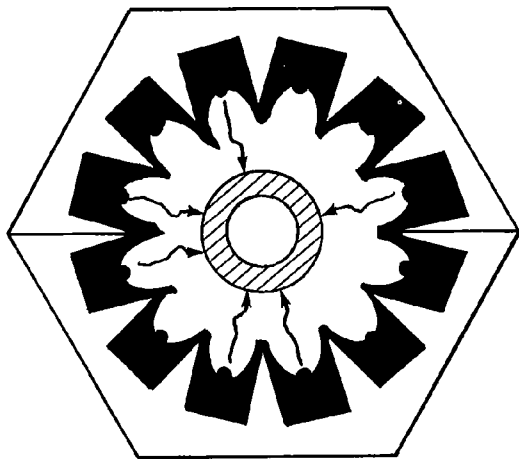


Figure 23 — “Infrared Furnace” of Lamp Reflector Units, Clamshelled or Assembled Around Pipe

**Table 2
Typical Quartz Lamps**

<u>Lighted Length</u>		Rated Volts	Watts (W)	W/in.	W/mm
in.	mm				
<u>Tungsten Filament Lamps</u>					
5	127	120	500	100	4.0
6	152	144	1200	200	8.0
10	254	240	1000	100	4.0
10	254	240	2000	200	8.0
16	406	240	1600	100	4.0
13-3/4	349	384	3200	230	9.0
<u>Iodide Cycle Lamps</u>					
2-1/2	63	120	1000	400	16.0
3	76	120	500	170	6.6
6	152	208	1250	210	8.2
9-3/4	248	480	6000	620	24.0

These lamps can be used with any of a variety of reflectors, and the reflector package may or may not be designed to accommodate circulating water or gas flow cooling, to make a heating unit with the desired temperature-time capability for the work load.

At rated power output, lamps should have a life of approximately 3000 “on” hours or several thousand typical four-hour thermal cycles. Typical lives of one year are common in practical heating applications. A modulated current control system will extend the life of lamps when compared to an on-off control system.

8.3.2 Reflectors. Reflectors are available in ceramic, gold, or polished aluminum. Gold is generally reserved

for applications requiring higher temperatures than those encountered in local heat treatment of welds. For the latter, aluminum or ceramic is adequate. The advantage of the ceramic reflector is that, although its initial efficiency is somewhat lower than metal reflectors, the efficiency is maintained constant throughout service. If the ceramic is dulled, it can be rehabilitated by exposing it to high temperature to drive off any condensed contamination. This will happen to some extent in normal operation, giving the ceramic a stabilizing, self-cleaning feature. The aluminum reflector should have an efficiency of up to 95% depending primarily on cleanliness and polish. The ceramic has an efficiency of 90%.

The metal reflectors, particularly aluminum, will generally require some cooling, either water or forced gas. This adds to the complexity of the setup. Air used to cool reflectors can cool the pipe if it is not protected. Ceramic reflectors may be used without cooling.

8.3.3 Thermal Cycle Control. The primary method for measuring temperature as an input to the feedback control is a chromel-alumel thermocouple; the method for attaching the thermocouple is similar to that described in 2.2.2. The thermocouple bead should be attached to the pipe near the weld being heated and should be protected from direct radiation from the lamps. This temperature signal is then compared to a desired signal, and the lamp power input is varied accordingly. Control devices can be as simple as on-off, but the preferred method adjusts power to match the actual versus desired temperature differential to control heat-up rate, dwell time, and cool-down rate. This would include a variable reactance or proportional voltage control feature, similar to the better furnace thermal control devices. In a sense, one builds a furnace around a pipe for radiant quartz lamp heating.

8.3.4 Effect of Work Surface Condition. As indicated previously, the work must be an infrared absorber rather than an efficient reflector. Thus, blackening the surfaces will enhance efficiency of the radiant process. Variations in blackness or reflectivity are the primary reason for the requirement for feedback control for each stress relief cycle.

Variations in piping surface condition can be expected; thus, a repetition of the same power-time cycle will not necessarily produce the same temperature-time cycle. Figure 24 indicates, for example, the difference in heating rates which can be experienced comparing an oxidized with a nonoxidized surface of material exposed to the infrared radiant heat. As seen, the oxidized material, being a more efficient absorber, heats appreciably faster; oxidation which occurs during the stress relief cycle assists the thermal efficiency of the procedure.

There will be other variations due to power input and metal mass.

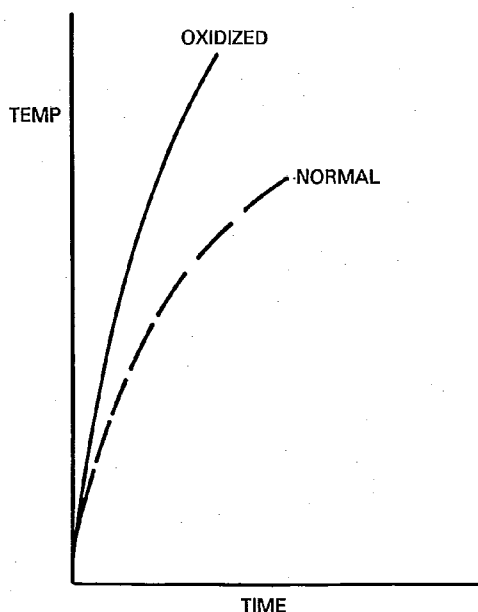


Figure 24 — Heating Rate Variation with the Target Surface

8.4 Relative Advantages and Disadvantages of Quartz Lamp Radiant Heating. The relative advantages of quartz lamp radiant heating for preheating or postheating are the following:

- (1) Fast response time. This procedure will generally allow heating at rates limited only by the need to reduce the through thickness temperature differential in the pipe itself.
- (2) Efficiency. Quartz lamp and reflector efficiencies are both quite high. Most of the heat goes into the work.
- (3) Cleanliness. No combustion products are brought in contact with the work. Inert gas may be flushed through the work area during heating. Operator comfort is high since waste heat is low.

(4) Fast cool down. Little or no extra mass is brought to temperature. Thus, the part or work can cool as fast as its own heat capacity and thermal conductivity will allow, provided the procedure specification permits such rapid cooling.

(5) Quick turn-around. An established procedure can be performed with expeditious set up and processing.

The disadvantages of quartz lamp radiant heating include the following:

- (1) Initial equipment cost is high.
- (2) Quartz lamps are fragile and sensitive to contamination. They must be kept clean and protected from rough handling.
- (3) Separate "furnaces" must either be fabricated or available for each pipe diameter. However, this can be nullified by using a single large size furnace, or by using lamp units as building blocks.

9. Comparison of Heating Processes

No one local heat treating process is superior for all applications. The process best suited to any given job depends on the circumstances.

10. Safety and Health

This standard does not attempt to give detailed coverage to all safety and health hazards. However, pertinent information can be found in the following documents.

- (1) ANSI/ASC Z49.1, *Safety in Welding and Cutting*
- (2) NFPA No. 70, *National Electrical Code*
- (3) *Code of Federal Regulations (CRF)*, Title 29, Chapter XVII, Part 1910
- (4) Manufacturer's safety manuals and instructions on all equipment and material used

These documents shall be referred to and complied with as required.

Appendix

Document List

(This Appendix is not a part of ANSI/AWS D10.10-90, *Recommended Practices for Local Heating of Welds in Piping and Tubing*, but is included for information purposes only)

The following is a complete list of the documents prepared by the AWS Committee on Piping and Tubing:

- AWS D10.4 Austenitic Chromium-Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding
- AWS D10.6 Titanium Piping and Tubing, Recommended Practices for Gas Tungsten Arc Welding
- AWS D10.7 Aluminum and Aluminum Alloy Pipe, Recommended Practices for Gas Shielded Arc Welding
- AWS D10.8 Chromium-Molybdenum Steel Piping and Tubing, Recommended Practices for Welding
- AWS D10.9 Qualification of Welding Procedures and Welders for Piping and Tubing, Specification for
- AWS D10.10 Local Heating of Welds in Piping and Tubing, Recommended Practices for
- AWS D10.11 Root Pass Welding of Pipe without Backing, Recommended Practices for
- AWS D10.12 Low Carbon Steel Pipe, Recommended Practices and Procedures for Welding