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A TECHNIQUE FOR MAKING CLEAN HOLES IN METALLIC PIPING AND COMPONENTS

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16. Abstract

Testing was conducted to develop a technique of providing clean holes in process piping or in a metal surface accessible from one side only without disassembling the system. The method was performed on sample pieces of piping and worked successfully with no contaminants being found on the inside of the pipe. The materials tested were Inconel 600, 304 stainless steel, Hastelloy X, and ASTM-A53 "black" steel. The technique was developed such that it could be done in the field with hand-held power tools and a portable tungsten inert gas welding machine.

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A TECHNIQUE FOR MAKING CLEAN HOLES IN METALLIC PIPING AND COMPONENTS

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SUMMARY

Testing was conducted to develop a technique of providing clean holes in process piping or in a metal surface accessible from only one side without disassembling the system. The method was performed on sample pieces of piping and worked successfully with no contaminants being found on the inside of the pipe. The materials tested were Inconel 600, 304 stainless steel, Hastelloy X, and ASTM-A53 "black" steel. The technique was developed so that it could be done in the field with hand-held power tools and a portable tungsten inert gas welding machine.

INTRODUCTION

In many piping systems and components it often becomes necessary to install new instrumentation and/or auxiliary lines to the system after it has been assembled. Thermocouples, pressure probes, and vacuum sensors are types of instrumentation that are often added to assembled systems. Auxiliary lines may be used as a bypass flowline or for a system fluid sampling station. In most systems contaminants like metal chips and cutting oils are detrimental to the system components. The metal chips can plug filters, cause flow disturbances, or destroy rotating components. In liquid metal systems the addition of air can oxidize the system fluid and cause severe line plugging.

In a system assembled with fittings the common method of making these access holes has involved the removal of the section of pipe. The access holes could then be drilled and the section cleaned and reinstalled in the system. This method, which involves considerable disassembly and reassembly work, does not entirely eliminate the contamination problem, especially with liquid metal systems. The possibility of creating system leaks at the joints where the system was taken apart also exists.

The common method of making access holes in a system that is welded has been to cut the section of pipe out of the system with a tubing cutter. The holes could then be drilled and the section cleaned and rewelded into the system. Two additional system welds are incurred using this method. At times it is not feasible to use a tubing cutter because of space limitations. In these cases, a hacksaw is used and the system in the area of the removed section is manually cleaned.

Many times it becomes necessary to have additional access holes in components or fabricated tanks that are not installed in a system. Drilling holes in these components and tanks introduces particles inside then that cannot be removed without performing elaborate cleaning procedures or complete disassembly.

The primary purpose of this investigation is to develop a technique of making clean holes in process piping and components with no system contamination. Consideration was given to being able to predict the minimum hole diameter after completion. Various types of materials and different pipe diameters and wall thicknesses were tested.

The technique developed involves three steps: preparation of a blind pilot hole in the piping wall, pressurizing the pipe or component with an inert gas to 5.1 to 12.7 centimeters (2 to 5 in.) of water, and completing the hole by applying a heat source to melt the remaining wall thickness. This technique has been successfully employed for installing additional gas stream thermocouples and system inspection ports in a research test loop.

APPARATUS AND PROCEDURE

Controlled laboratory experiments were performed with sample pieces of piping employed in existing test loops to develop the technique of making clean holes. The basic idea of this technique is to remove as much of the pipe wall thickness as possible at the desired hole location by drilling a blind pilot hole, pressurizing the inside with an inert gas, and then removing the remaining wall thickness with a heat source. The result of this procedure is a clean hole with no buildup of metal on the inner wall.

The materials tested with Inconel 600, 304 stainless steel, Hastelloy X, and ASTM-A53 "black" steel. Various diameters and wall thicknesses of each material were tested. The tools used were portable so they could be operated in constricted work areas for infield applications. The tools included an ultrasonic flaw thickness tester, variable speed electric hand drill, water manometer, tungsten inert gas welding machine, inert gas supply 0.95-centimeter (3/8-in.) end mill, ball-type rotary file, depth micrometers, drill stops, and various sizes of drills.

Blind Pilot Hole Preparation

Because of its portability for infield applications, an electric hand drill is used to drill the blind pilot hole (fig. 1). The pilot hole is drilled partially through the wall to a diameter of 0.95 centimeter (3/8 in.). From experience it was found that 0.95 centimeter (3/8 in.) is the optimum size for the pilot hole diameter. A 0.95-centimeter (3/8-in.) two-fluted end mill is used to spot face the bottom of the pilot hole. The end mill is used because it does not chatter when drilling with a hand drill and it retains its cutting edge. Drill stops are used on all drills and the end mill to limit the depth of the pilot hole. After spot facing, the pilot hole is countersunk with a ball-type rotary file to provide an area where the molten metal from the bottom of the hole can flow. A rotary file is used because it can be controlled well in a hand drill. The "ball-type" rotary file was chosen because, due to its radius, it removes more metal than a standard countersink. Figure 2 is a sectional drawing of a typical blind pilot hole. The small step between the bottom of the countersunk area and the bottom of the pilot hole is a result of the radius of the rotary file. The ball touches the bottom of the pilot hole at this point (fig. 2).

Figure 1. - Field drilling a blind pilot hole.

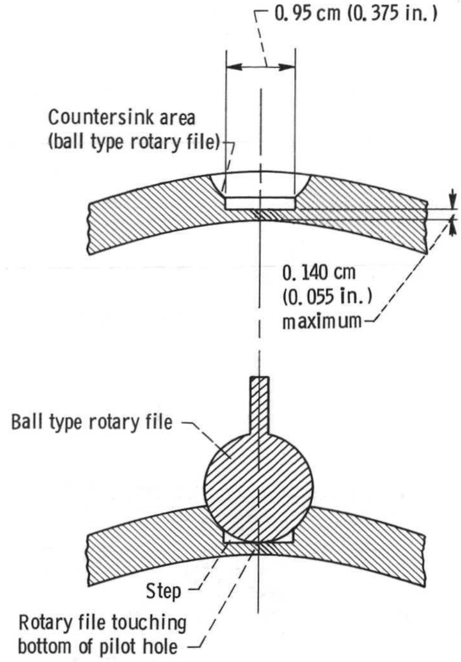


Figure 2. - Sectional view of typical blind pilot hole.

Pressurization and Hole Melting

An auxiliary supply of argon gas is used to pressurize the system. A rotometer flow regulator is used to control the flow of gas to the inside of the pipe and thus the internal pressure, which was measured with a water tube manometer. The heat source used is a tungsten inert gas welding machine with a foot-operated heat control.

For pipes and containment vessels having wall thicknesses greater than 0.165 centimeter (0.065 in.) a blind pilot hole is necessary. The internal pressure is set to 12.7 centimeters (5 in.) of water for the initial hole-melting phase. At this pressure the arc of the welding machine is struck in the bottom of the pilot hole (fig. 3). This melts the metal at the bottom of the pilot hole and it flows to the side of the countersunk area. As soon as this initial hole is formed, the arc is removed. In order to enlarge the hole, the pressure is adjusted to approximately 2.5 centimeters (1 in.) of water and the arc reinitiated. The arc is moved around the edge of the initial hole, rolling more of the metal into the countersunk area (aftermelt). During this enlargement of the hole, the inert gas flow is manually controlled to maintain the system internal pressure of approximately 2.5 centimeters (1 in.) of water. This process was performed until the hole reached the desired diameter.

Thin-walled pipes or containment vessels are defined as those having a wall thickness of 0.165 centimeter (0.065 in.) or less. For these thin-walled containers, no pilot hole preparation is made and no aftermelt is performed. The size of the final hole is

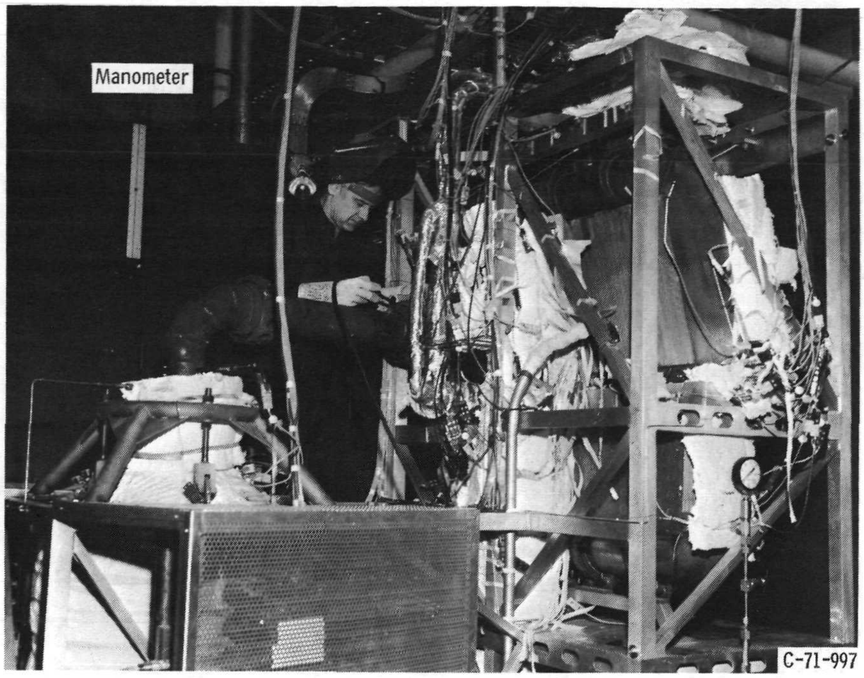


Figure 3. - Field heliarc application for hole melting phase.

governed by the internal pressure during the melting phase. After the internal pressure, 5.1 to 7.6 centimeters (2 to 3 in.) of water, has been set, the arc is struck and moved in the desired area at a low-heat level. After a few seconds the heat is increased and the hole is formed.

After the technique was established to make the clean holes, the position of the sample pieces was varied to simulate infield conditions. The position effect was only studied in the melting phase to determine the effect of gravity on the molten metal. Three positions were tested: vertically downward, vertically upward, and horizontally. These are shown in figure 4 as A, B, and C, respectively.

The pipe wall thickness on the sample pieces of piping was measured with micrometers. On the process piping where this method was used, the pipe wall thickness was determined on a system schematic and double checked with an ultrasonic flaw-thickness tester. This tester can measure the thickness of a pipe wall, from the outside, electronically and is accurate to ±0.013 centimeter (±0.005 in.) on the 2.5-centimeter (1-in.) range. This accuracy is well beyond that needed for this technique. The ultrasonic flaw-thickness tester can also be used to determine the thickness of an unknown section of pipe in a system where no accurate schematic exists.

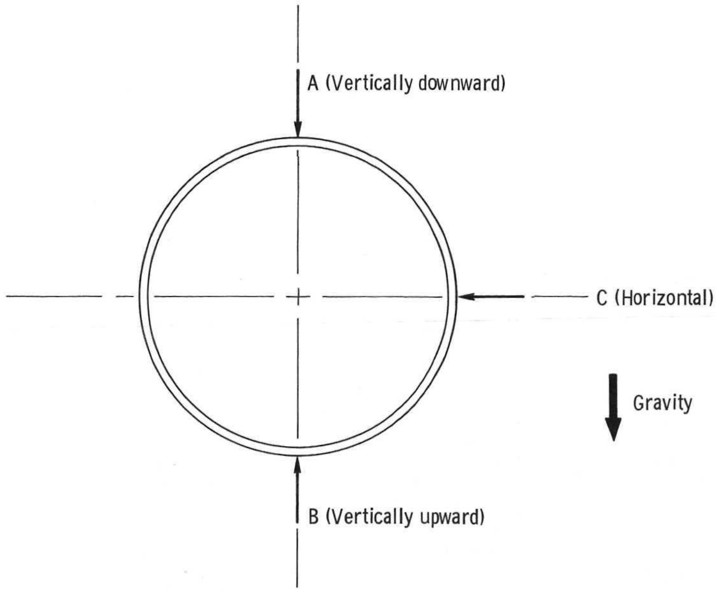


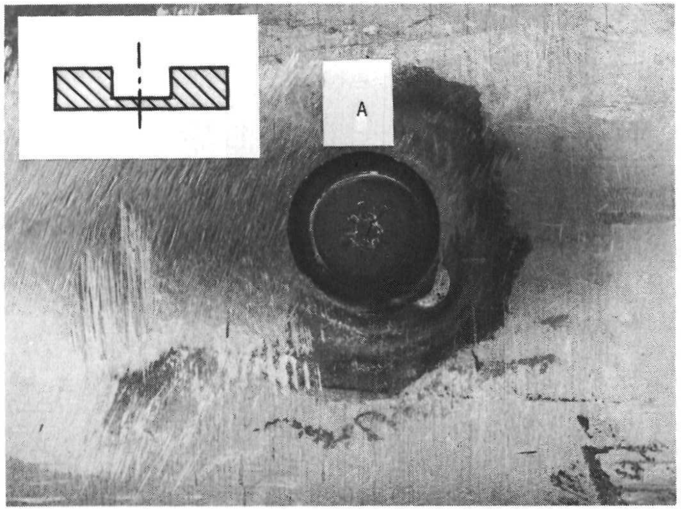
Figure 4. - Pipe positioning with respect to gravity.

DISCUSSION

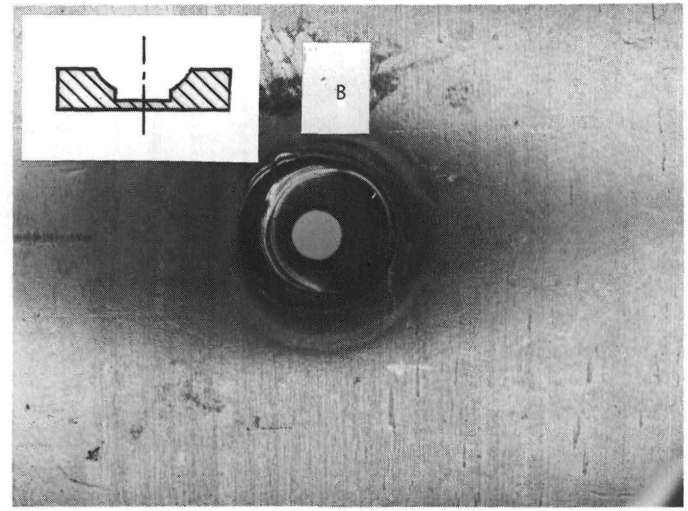
Controlled laboratory-type experiments were conducted to develop a technique to make clean holes in process piping without dismantling or cutting the system apart. Initial tests were performed to determine the feasibility of making the holes without contaminating the system. Tests were also conducted to determine methods and tools necessary to perform this operation in field conditions. Prime importance was placed on preventing any type of system contamination during the hole-making process. The results of this investigation are discussed herein. Many factors affect the hole size: the angle and depth of countersinking, the remaining metal thickness to be melted, the internal gas pressure, and the aftermelt. Because of these effects, it is suggested by the author that a sample piece with the correct dimensions be employed before using this technique on a component or system.

Effect of Angle and Depth of Countersinking

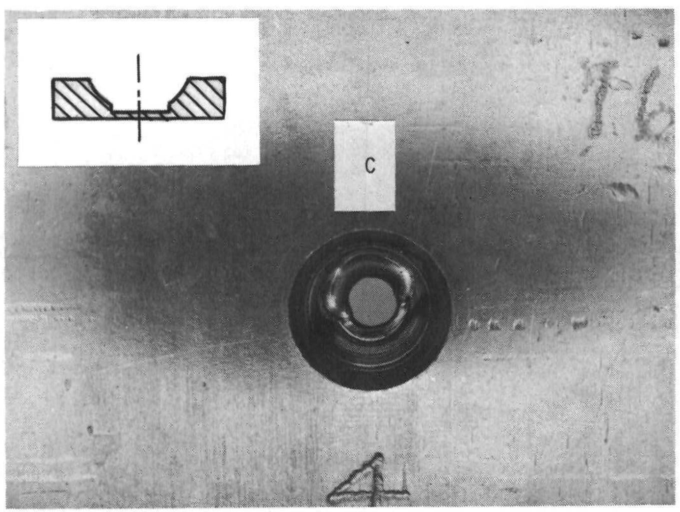
For thick-walled containment vessels the angle and depth of countersinking in the preparation hole determined the flow mechanism of the molten metal and, therefore, influenced the size of hole obtained. Figure 5 illustrates the influence of the angle and depth of the countersinking on the hole size. The photographs were taken with the resulting hole being directly opposite the camera lens. The four tests in figure 5 were in



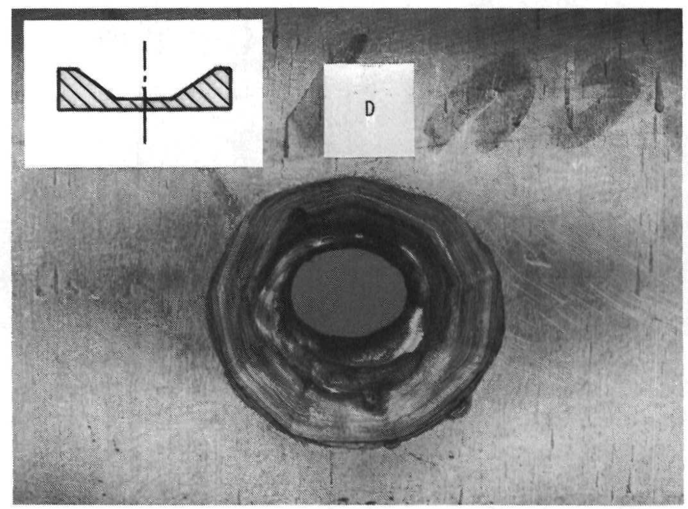
(a) No countersink used; no hole formed.



(b) Countersink used, 1.3-centimeter (0.5-in.) ball-type rotary fill; maximum hole diameter, 0.356 centimeter (0.140 in.); countersink area filled with metal.



(c) Countersink used, 1.6-centimeter (0.625-in.) ball-type rotary file; maximum hole diameter, 0.356 centimeter (0.140 in.); countersink area only partially filled with metal.



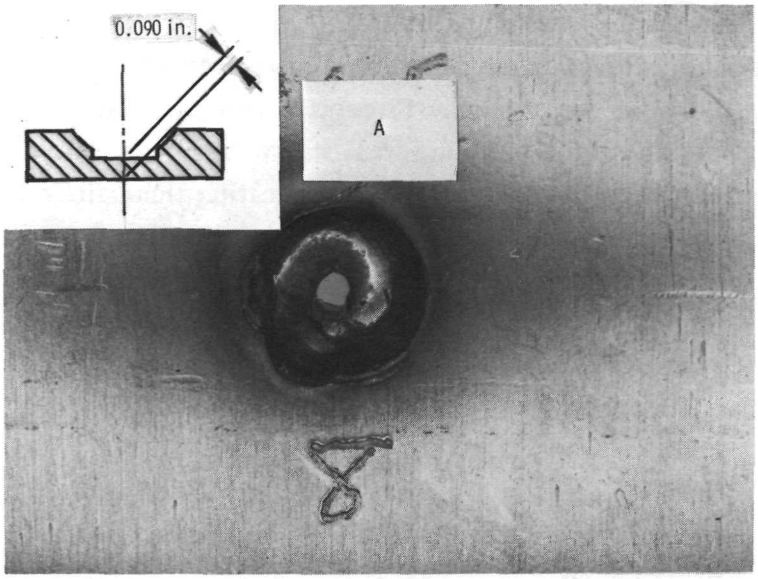
(d) Countersink used, 2.5-centimeter (1-in.) drill; maximum hole diameter, 0.673 centimeter (0.265 in.).

Figure 5. - Effect of angle and depth of countersinking on hole size. Sample size, 0.63- centimeter (0.25-in.) Inconel tube; remaining metal, 0.140 centimeter (0.055 in.); pilot hole diameter, 0.95 centimeter (0.375 in.).

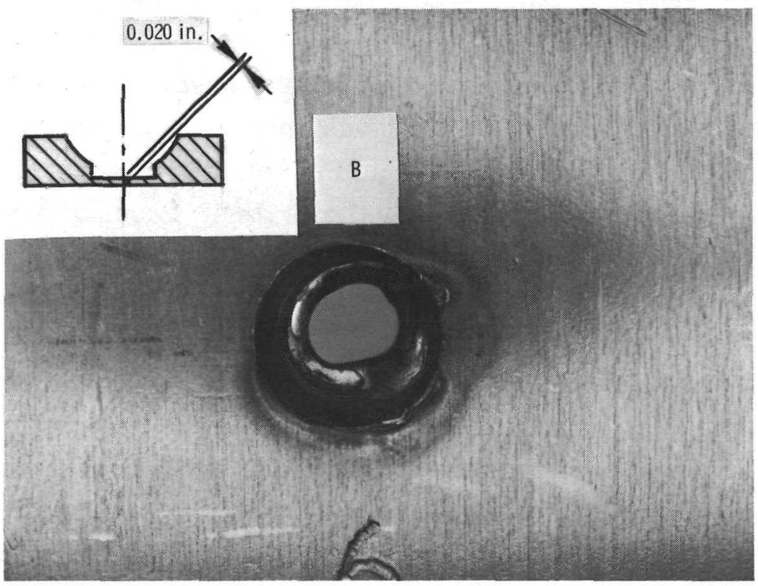
the same 12.7 (o.d.) by 0.63 centimeter (5 by 0.25 in.) wall Inconel tube. Each pilot hole was drilled with a 0.95-centimeter (3/8-in.) drill and spotfaced with a 0.95-centimeter (0.375-in.) end mill to within 0.140±0.013 centimeter (0.055±0.005 in.) of the inner wall. The internal pipe pressure during the hole-melting phase was about 12.7 centimeters (5 in.) of water for all four holes. Hole A in figure 5 had no countersink used. As can be seen, no hole was formed. The metal from the edge of the pilot hole melted and flowed to the bottom of the pilot hole before a hole could be formed. This increased the metal thickness at the bottom of the pilot hole. The countersink used for hole B in figure 5 was a 1.3-centimeter (0.5-in.) diameter ball-type rotary file. The metal from the bottom of the pilot hole flowed into the countersink area forming a hole in the tube. The size of the hole was limited to 0.356-centimeter (0.140-in.) diameter because the small countersink area was filled with metal. Continued application of heat (aftermelt) did not increase the hole diameter. Hole C in figure 5 was countersunk with a 1.6-centimeter (0.625-in.) ball-type rotor file. No aftermelt was performed after the initial hole was formed so as to illustrate the effect of the large countersink. The metal from the bottom of the pilot hole flowed to one side of the countersink. The hole diameter is 0.356 centimeter (0.140 in.). A small amount of aftermelt could easily increase this hole diameter by flowing more metal from the edge of the initial hole into the countersink area. Hole D in figure 5 was countersunk using a 2.5-centimeter (1-in.) diameter drill. The maximum diameter of the hole, after some aftermelt, was 0.673 centimeter (0.265 in.) in diameter. This large diameter is attributed to the large angle of the countersink and the fact that the metal could easily flow into the countersink area.

Effect of Metal Thickness to be Melted

The thickness of metal remaining between the bottom of the pilot hole and the inner wall also influenced the final hole diameter. The thinner the metal left at the bottom of the pilot hole, the larger the hold diameter obtainable - up to 0.95 centimeter (0.375 in.). This was because less metal had to be melted and removed during the melting phase. Thicknesses of 0.013 to 0.025 centimeter (0.005 to 0.01 in.) made it easy to form a large hole, and thicknesses above 0.228 centimeter (0.09 in.) made it very difficult to form good holes. Hole A in figure 6 was made in the 12.7 (o.d.) by 0.63 centimeter (5 by 0.25 in.) wall Inconel tube. The pilot hole diameter was 0.95 centimeter (0.375 in.), and the countersink used was the 1.6-centimeter (0.625-in.) rotary file. The thickness of the metal between the bottom of the pilot hole and the pipe inner wall was 0.228 centimeter (0.090 in.). The final hole diameter was only 0.206 centimeter (0.081 in.). The large amount of metal that was melted in the bottom of the pilot hole filled the countersink area. Aftermelt would not increase the hole diameter. The pilot



(a) Remaining metal thickness, 0.228 centimeter (0.090 in.); maximum hole diameter, 0.206 centimeter (0.081 in.).



(b) Remaining metal thickness, 0.051 centimeter (0.020 in.); maximum hole diameter, 0.475 centimeter (0.0187 in.).

Figure 6. - Effect of remaining metal thickness on hole size. Sample, 0.63-centimeter (0.25-in.) Inconel tube; pilot hole diameter, 0.95 centimeter (0.375 in.); countersink used, 1.6 centimeter (0.625 in.) ball type rotary file.

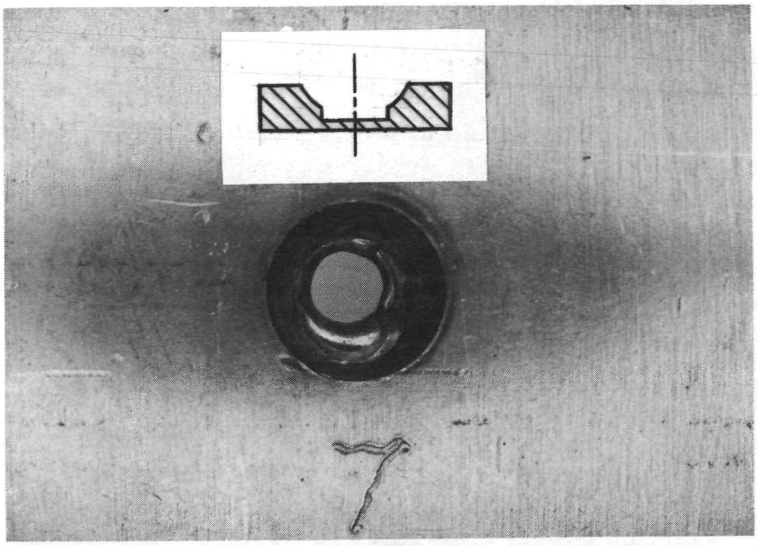
hole for hole B in figure 6 was the same as hole A except that the thickness of metal between the bottom of the pilot hole and the tube inner wall was 0.051 centimeter (0.020 in.). All other conditions were the same for both holes. The final hole diameter was much larger, measuring 0.475 centimeter (0.187 in.). This illustrates how a larger hole can be made when the metal is thin between the bottom of the pilot hole and the inner wall. A thickness of 0.140±0.013 centimeter (0.055±0.005 in.) between the bottom of the pilot hole and the pipe inner wall was chosen for this technique. This thickness was a compromise between the ease of melting through and a safety margin to keep from breaking through the tube wall during the drilling process. This thickness, combined with the proper countersink, formed very predictable holes.

Effect of Internal Gas Pressure

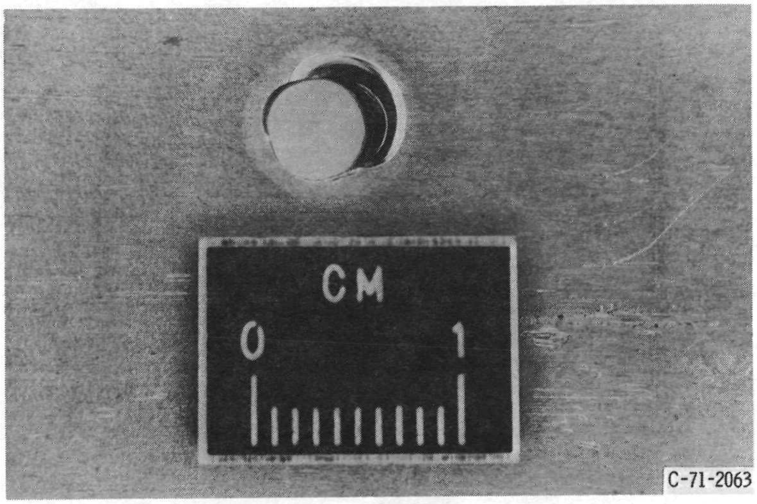
Components having thick walls, 0.165 centimeter (0.065 in.) or more, where a pilot hole is necessary, require a pressure of 13 centimeters (5 in.) of water or more during the initial melting phase. This pressure prevents any metal from flowing into the pipe when the hole is first blown. An upper limit of 18 centimeters (7 in.) of water was made to prevent the metal from spurting out of the hole when the initial hole was formed. After the initial hole was made, the pressure within the pipe was reduced to 2.5 centimeters (1 in.) of water for the aftermelt phase. This pressure maintained a metal flow to the outside of the tube as heat was applied to the edge of the initial hole. The pressure in the tube tends to decrease as the hole diameter increases but should be maintained at about 2.5 centimeters (1 in.) of water. Pressures below this allow a small buildup of metal on the inside of the pipe around the hole. The maximum pressure during this phase is limited to 5.1 centimeters (2 in.) of water because, above this pressure, the welding arc is blown out by the gas escaping through the hole.

In thin-walled pipes and components, less than 0.165 centimeter (0.065 in.), the hole diameter is controlled only by the internal pressure during the initial melting phase. No aftermelt is performed on these thin-walled vessels to increase the hole diameter. A pressure of 5.1 centimeters (2 in.) of water resulted in about a 1.3-centimeter (0.5-in.) diameter hole. A 0.95-centimeter (0.375-in.) diameter hole is obtained with an internal pressure of 7.6 centimeters (3 in.) of water. The arc of the welder is applied at a low heat level for 4 or 5 seconds to preheat the metal. The heat is then increased to its full level to form the hole.

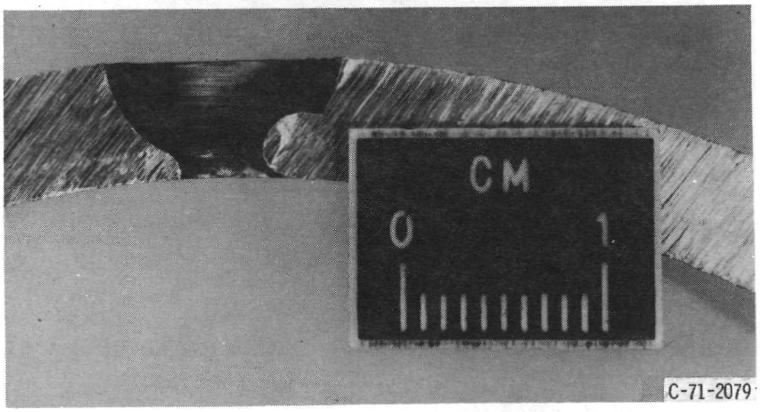
At no time during testing were any contaminants introduced into the inside of the pipe. The melted metal always flowed to the outside of the pipe because of the internal gas pressure. The photographs of figure 7 illustrate this. Figure 7(a) shows an outside view of the hole with the metal laying in the side of the countersunk area. Figure 7(b) is of the inside of the tube showing that there was no buildup of metal around the hole.



(a) Outside of tube.



(b) Inside of tube.



(c) Cross sectioned tube at hole center.

Figure 7. - Photographs of typical hole showing that no metal flows to inside. Sample, 0.63 centimeter (0.25 in.) Inconel tube.

Figure 7(c) was taken after the tube had been sectioned with a saw through the center of the hole. This shows how the countersunk area of the pilot hole preparation holds the molten metal. Movies were taken during the melting phase of both the inside and outside of the tube. These movies verify that no metal or oxide particles entered the tube.

Effect of Piping Materials

The effect of the materials used was significant only in the forming of the pilot holes. As expected, the stainless steel drilled harder than the ASTM-A53 "black" steel and the Inconel was the hardest to drill. The internal pressures were not varied for the different materials. No procedures were changed for the different materials during the melting phase. The tungsten inert gas welding machine that was used to melt the metal from the bottom of the pilot hole was set up suitably for normal welding operation for the metal being tested.

Effect of Aftermelt

The diameter of the hole can be controlled by the amount of aftermelt performed. The side of the initial hole is small because the heat is concentrated in the center of the pilot hole. The hole diameter can then be increased to its desired size by moving the arc around the edge of the initial hole (aftermelt). The size of the hole can be increased by this method to the limit dictated by the diameter of the pilot hole and the angle of the countersink. During the aftermelt phase, the heat of the welder was varied to concentrate more heat in areas where the metal was thicker.

Effect of Work Piece Position

The position of the pipe during this process had little effect when the internal pipe pressure was set as described earlier. The only effect noted was when the desired hole was in the horizontal position shown as C in figure 4. In this position, all of the metal from the bottom of the pilot hole flowed to the lower side of the countersunk area. This in turn shifted the final hole up from the original position of the pilot hole. This shift was not considered a problem since it was only a fraction of a centimeter. No other work piece position effects were noted.

CONCLUDING REMARKS

A technique for making clean holes in metal pipes, tubes, and components was established. The following observations were made:

1. Access holes can be made in process piping without any system contamination and without disassembling the system.

2. The process can be done in the field with hand-held power tools and a portable tungsten inert gas welding machine.

3. The hole size can be controlled by the diameter of the pilot hole, the angle of the countersink, the depth of the pilot hole, and the time and the area the heat is applied.

4. Piping position and material do not affect the process adversely.

5. This technique can be performed on any pipe or component if a suitable pilot hole can be made and it can be pressurized to a maximum of 13 centimeters (5 in.) of water.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 18, 1971,
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