

# HIGH FREQUENCY WELDING - THE PROCESS AND APPLICATIONS

By Robert K. Nichols, PE

Thermatool Corp.

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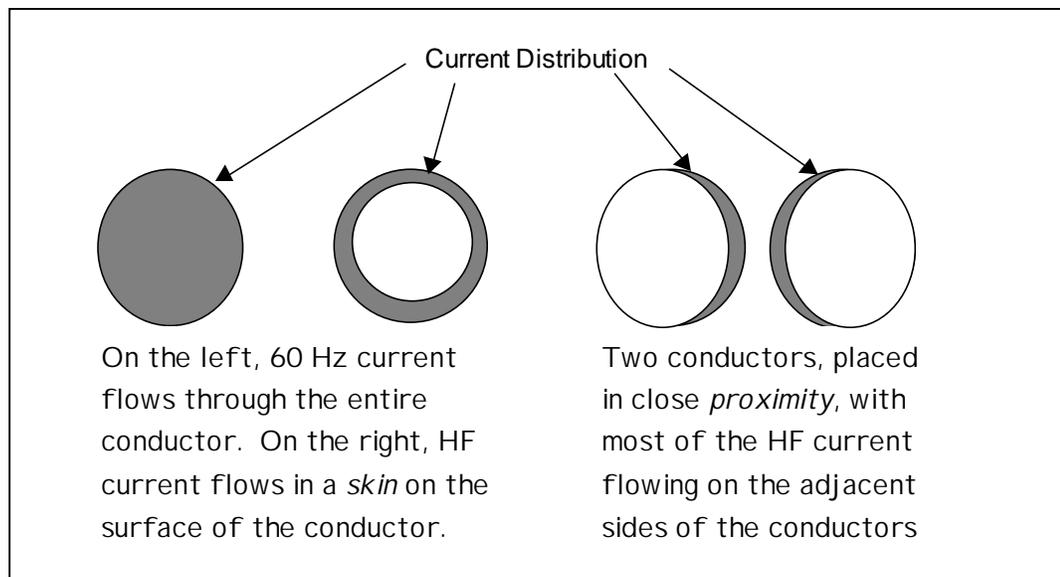
The High Frequency Welding Process is usually associated with welded tubular products. While this remains the most common application of this unique technology, other applications have been used successfully for many years.

## WHAT IS HF?

High Frequency, in these applications, is AC current alternating at between 100 and 800 Kilohertz (kHz), that is, 100,000 and 800,000 cycles per second. Until relatively recently, to boost the frequency of 60 cycle line current to HF, the AC current was converted to DC current, fed into a vacuum tube oscillator (triode) used in conjunction with a resonant tank circuit to maintain the output of high frequency power. Today, this is accomplished in a similar fashion using MOSFETs (Metal Oxide Silicon, Field Effect Transistors) in place of the triode.

## THE NATURE OF HF CURRENT

HF current has two very unusual features that distinguish it from 60 Hz line current. First, line frequency current flows through the entire conductor where HF current flows only on the surface of the conductor. This is called the **skin effect**. Second, when two conductors carrying HF current are placed close to one another, the current concentrates on the two adjacent surfaces of the conductors. This is called the **proximity effect**.



## FREQUENCY AND REFERENCE DEPTH

The depth of the “skin” that carries the HF current is a function of the material, material temperature and the frequency of the current. Generally, higher frequencies have shallower skin depths and lower frequencies have deeper skin depths. The skin depth is referred to as the **reference depth** and can be calculated with the following formula:

$$d = 3160 \sqrt{\rho / \mu f}$$

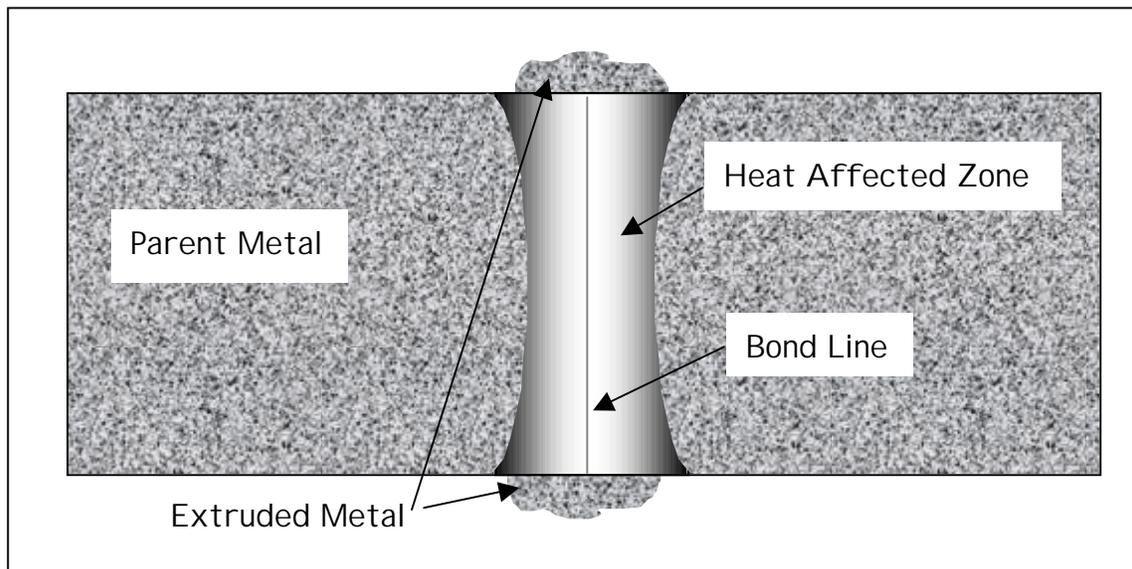
where  $d$  = reference depth

$\rho$  = resistivity in ohm-inches

$f$  = frequency in cycles per second

Note: 3160 is a constant for steel.

Most HF welds are “forge welds” in that they neither use a filler metal nor melt the edges together as do more conventional welding methods. The forge weld is accomplished first by applying the HF current to the edges, either by direct contact or induction coil. Next the edges are brought together under pressure forcing the liquid metal to be ejected from the bond plane. Lastly, the hot, unoxidized metal beneath the liquid metal on each edge metallurgically bonds to form the weld.



## SPEED AND POWER

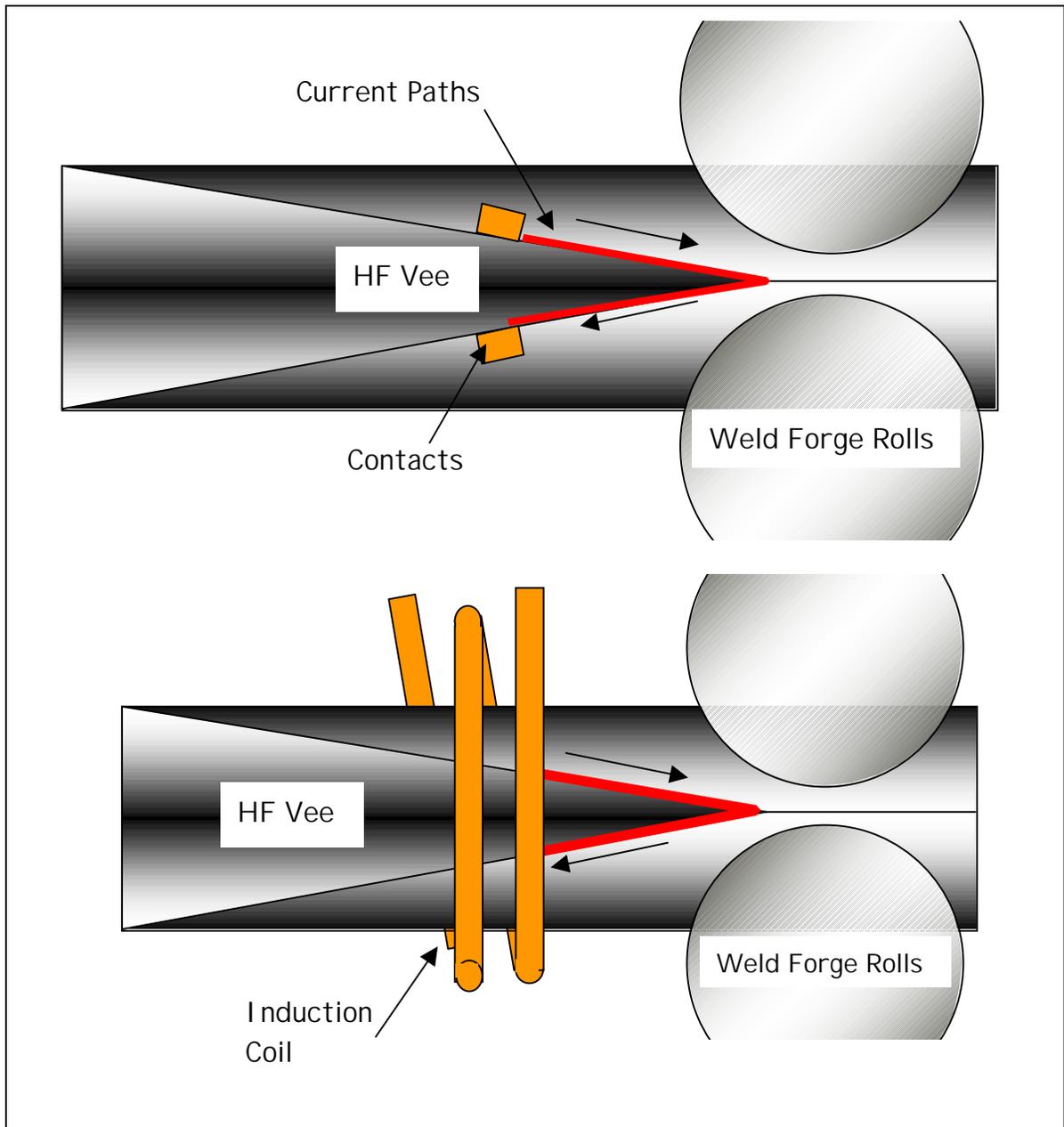
HF welders have been produced with power ratings from 60 kilowatts to over 1 megawatt. The tank circuits can be tuned for frequencies of 100 kilohertz to 1 megahertz. This broad range of frequency and power can be applied to pipe as large as 24" (610mm) diameter by .900" (22.9mm) wall running at 30 feet per minute (9.1

meters per minute) to 1" (25.4mm) diameter x .090" (2.3mm) wall running at 1000 fpm (304 mpm).

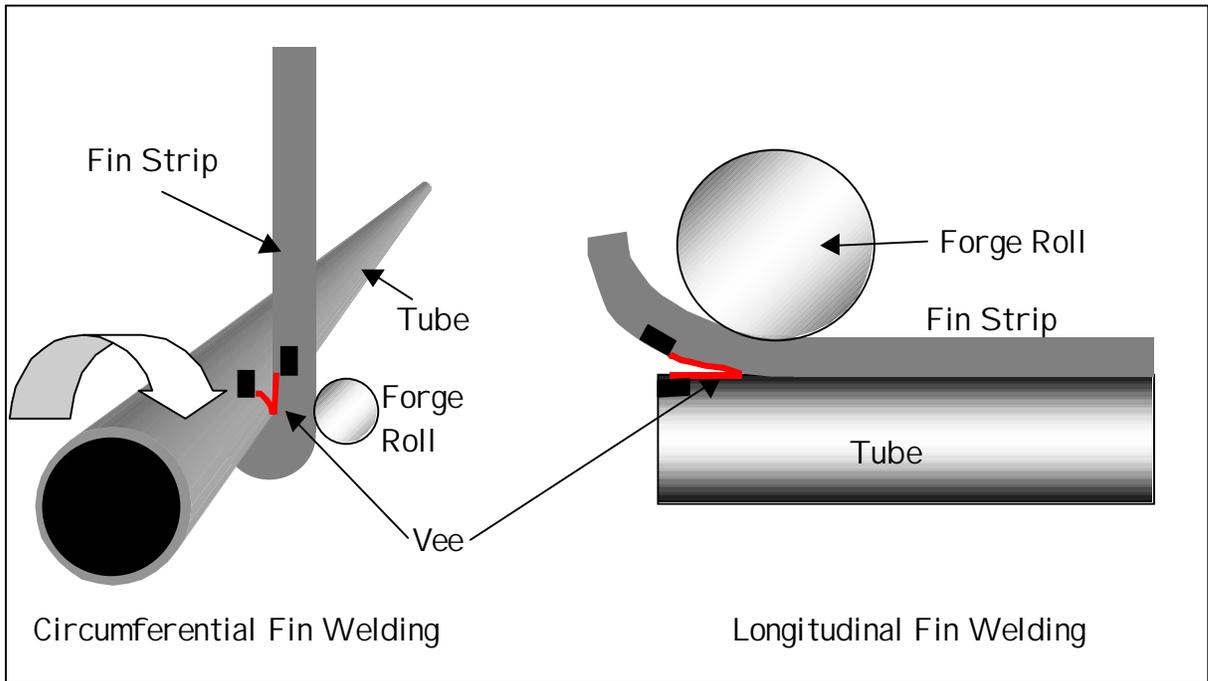
The HF process has been successfully applied to steel, copper, brass, aluminum, stainless steel, titanium, and gold. It can be applied to any electrically conducting material and in shapes other than tubular. For instance it has continuously welded structural I-beams from 3 separate coils of strip steel at 70 fpm (21 mpm). It can be used to weld a spiral fin onto a tube to make boiler tubes at 450 rpm. Many other examples are presented at the end of this paper.

### METHODOLOGY

Although the application varies, the basic principle of HF welding involves creating a "vee" where the two surfaces to be welded are brought together. The example below illustrates this in a tube welding application showing both the contact and induction method.

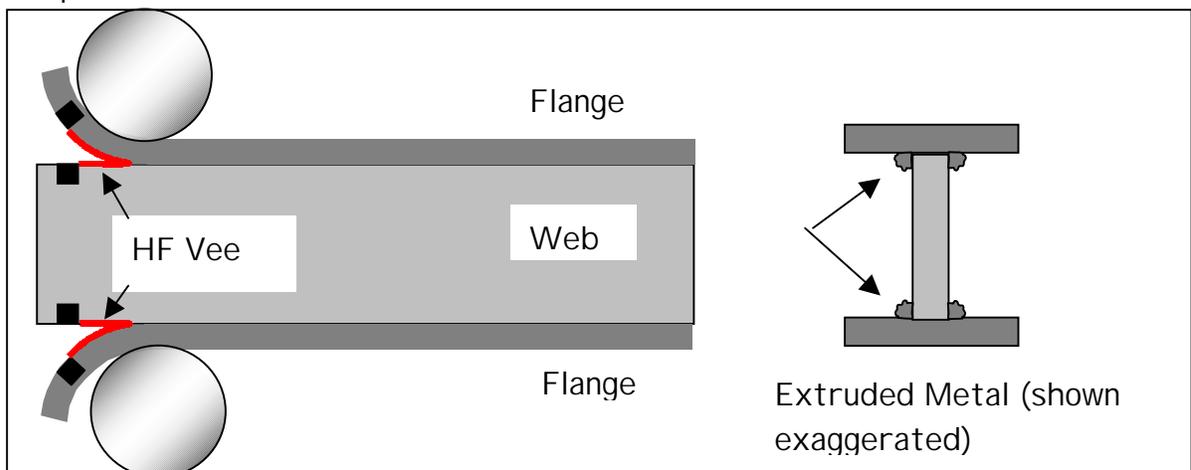


As the previous two illustrations show, forming the flat strip into a cylinder creates the HF vee. The edges are heated by the resistance of the HF current flowing in the edges of the vee. As they get closer, the contribution of the Proximity Effect concentrates the current and more heat is created until at the apex of the vee, the metal on the edge surface is molten. As the edges pass through the weld rolls, the molten metal is ejected and the forge weld is formed.



The above drawings illustrate how it is possible to create the HF vee in non-tubular shapes. Both methods are extensively used to manufacture finned tube for use in boilers and heat exchangers.

With just a slight modification to the fin welding technique, the HF process can be adapted to weld I-Beams and H-beams as shown below.

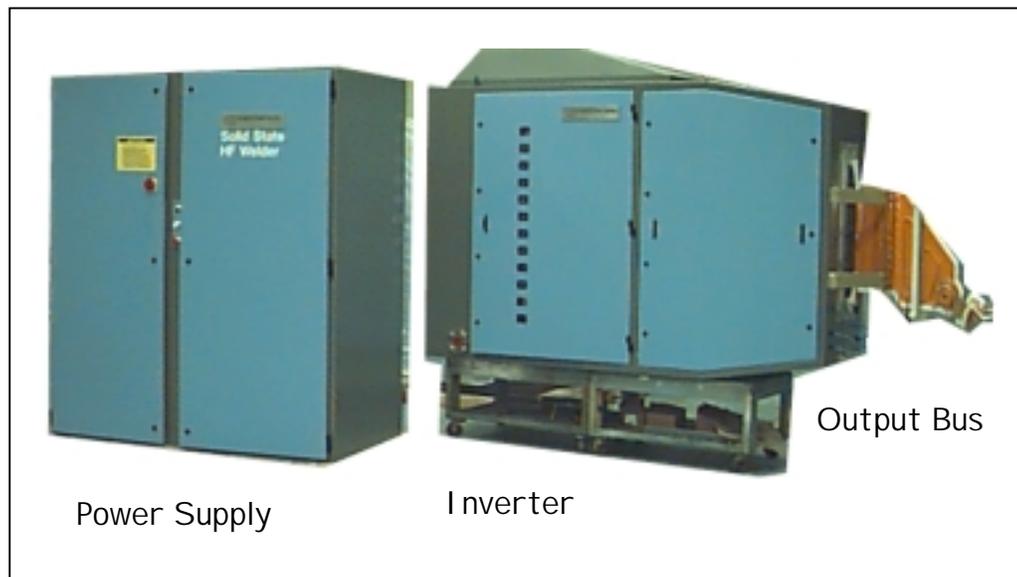


## THE HF VEE

To successfully utilize the HF process, the apex of the vee should be as near the weld point as possible. The degree of opening is influenced by the material being welded but is generally kept between 3 and 7 degrees. The edges should be kept parallel and flat as they approach one another. Any variation in vee length during the process will result in variations in heat and thus, weld quality.

## THE HF WELDER

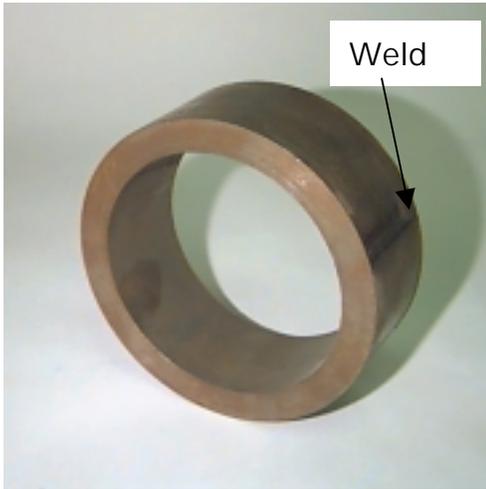
Shown below is a state-of-the-art Solid State HF welder. This system will supply up to 600 kW of power at a frequency of 100 kHz to 1MHz. Larger and smaller units are available from several manufacturers. In the pages following, you will find numerous examples from actual HF welding applications.



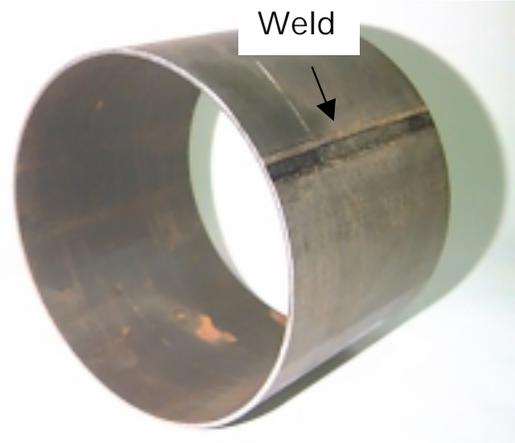
## HYDROFORMING APPLICATIONS

The renewed interest in tube hydroforming has prompted many people to supply tube to this market. Many have succeeded and a few have failed and those who fail usually cite "bad welds" as the problem. This is usually due to faulty set-up and execution of the HF weld. Done properly, with the care and attention demanded by any critical application, HF welded tube can be readily hydroformed. Low carbon contents seem to perform better although HSLA and stainless steels have been successfully hydroformed. Non-ferrous HF welded tubes are also easily processed. Seam annealing of the weld is not usually necessary but may improve the ductility in the Heat Affected Zone of higher alloy materials.

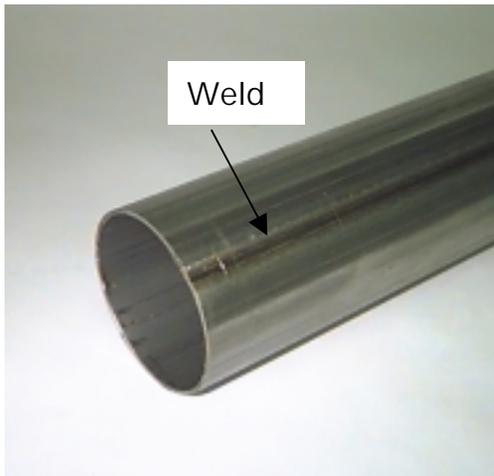
For further information or answers to questions about your specific application, please contact Robert K. Nichols, PE, Manager-Applications and Process Engineering for Thermatool Corp., 203-468-4281 or e-mail at [bohn@ttool.com](mailto:bohn@ttool.com).



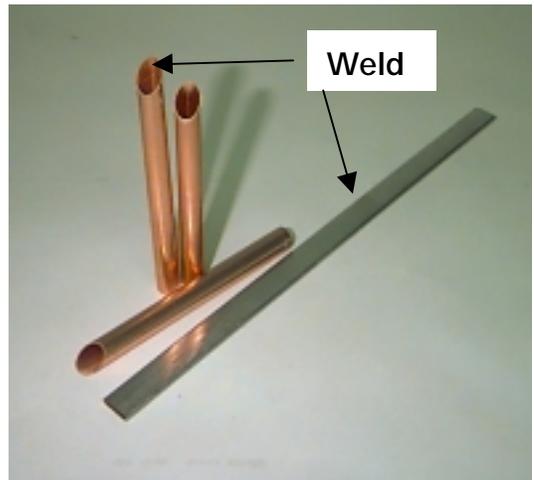
5-1/2" x .500 Wall Steel Pipe



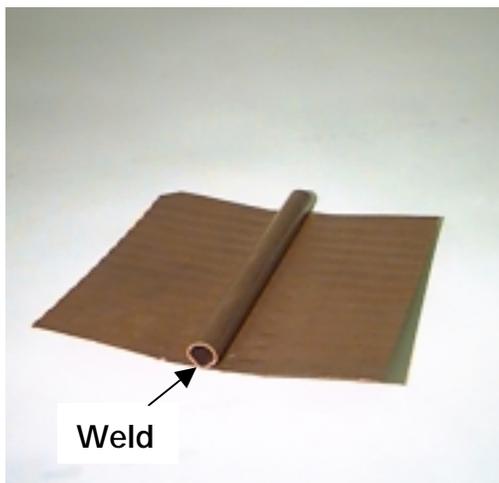
8-1/2" x .125 Steel Line Pipe



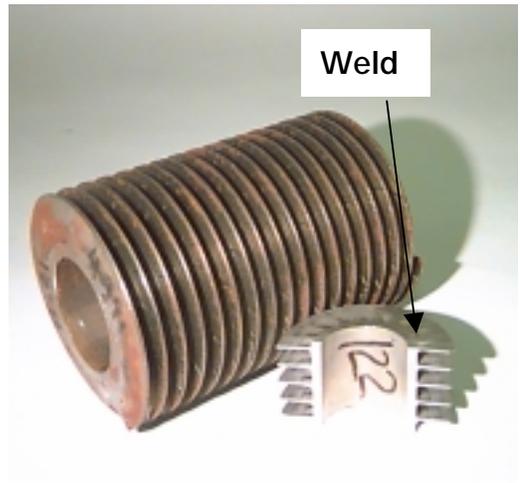
3" x .095 Stainless Exhaust Pipe



3/8" x .012" Copper Heat Exchanger Tube



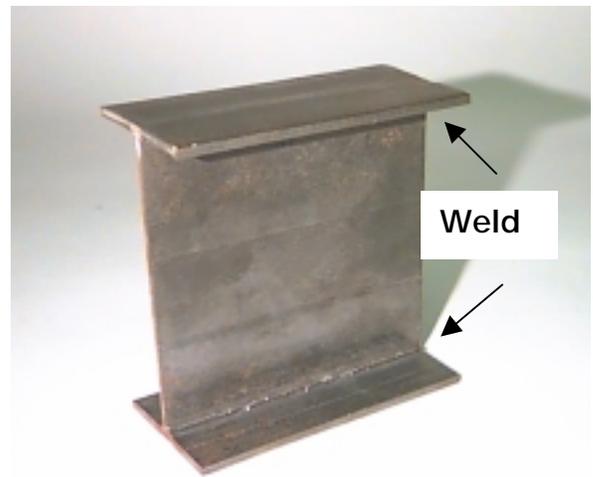
3/8" to .025" Copper solar panel



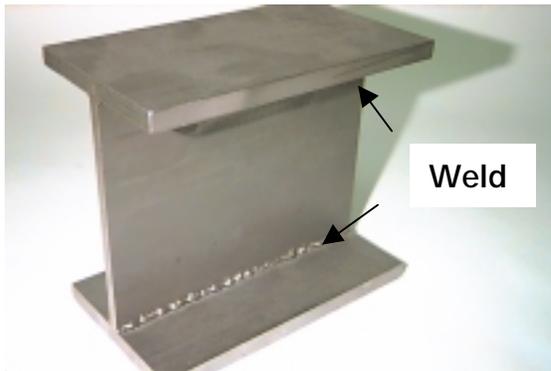
3" x .050 Steel fin boiler tube



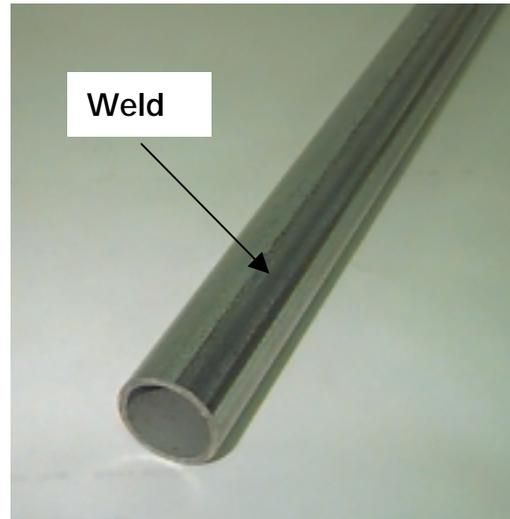
2.5" x .155" steel fin boiler tube



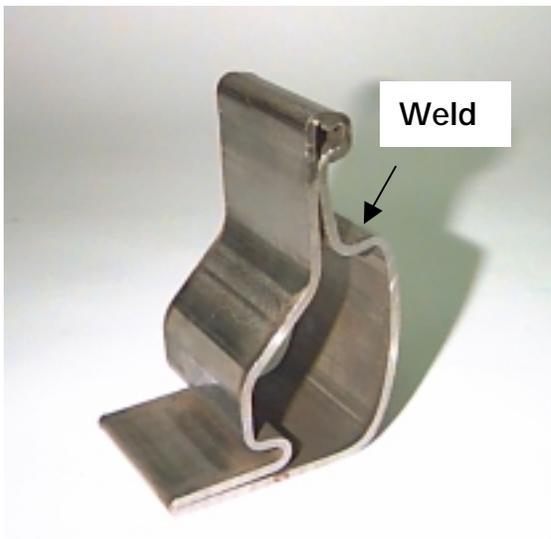
4.25"h x 2" w steel I-beam



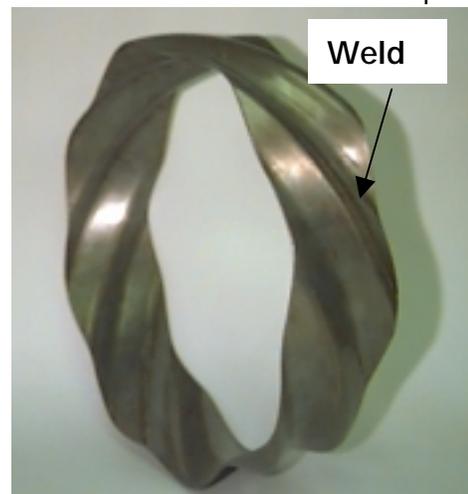
6"h x 4" w titanium I-beam



1.3" x .140" Galvanized Steel Pipe



4.25"h x .125" Roll Formed Beam



12" x .075 Galvanized Culvert Pipe



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