THERMATOOL CORP.

Welding Thick Wall, Small Diameter Tube

A Case Study

By:

Dr. Paul Scott
Vice President Technology
Thermatool Corp.
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Vice President, Technology – Thermatool Corp

General Observation:

We recently had the opportunity to help a customer weld 0.675-Inch diameter by 0.09-Inch wall tube. This is a very difficult tube to make. Most tube makers agree that tubes with a diameter to thickness ratio of less than 10 are difficult to manufacture. This tube has a diameter to thickness ratio of 7.5!! Therefore, practices that normally can be relaxed in the tube making process must be rigidly followed if high mill speeds are to be achieved.

Approach:

From a <u>tube</u> <u>welding</u> standpoint, the main problem to overcome is transferring sufficient power from the welder to the tube's weld Vee. This power transfer is accomplished by the magnetic field created by the welder's work and carried by the impeder. The amount of magnetic field required increases with the weld power requirement (mill speed x tube wall thickness). The amount of magnetic flux an impeder can carry is limited by the saturation flux level of the ferrite, the <u>total</u> cross-sectional area, and temperature. The magnetic flux required can be reduced by decreasing the area of the weld Vee (Vee length squared x Vee angle). These observations lead to the following criteria necessary to weld this tube at highest speed:

1. Use as large (diameter) an impeder as possible. A solid cross-section is preferable to one with a hole in the center.

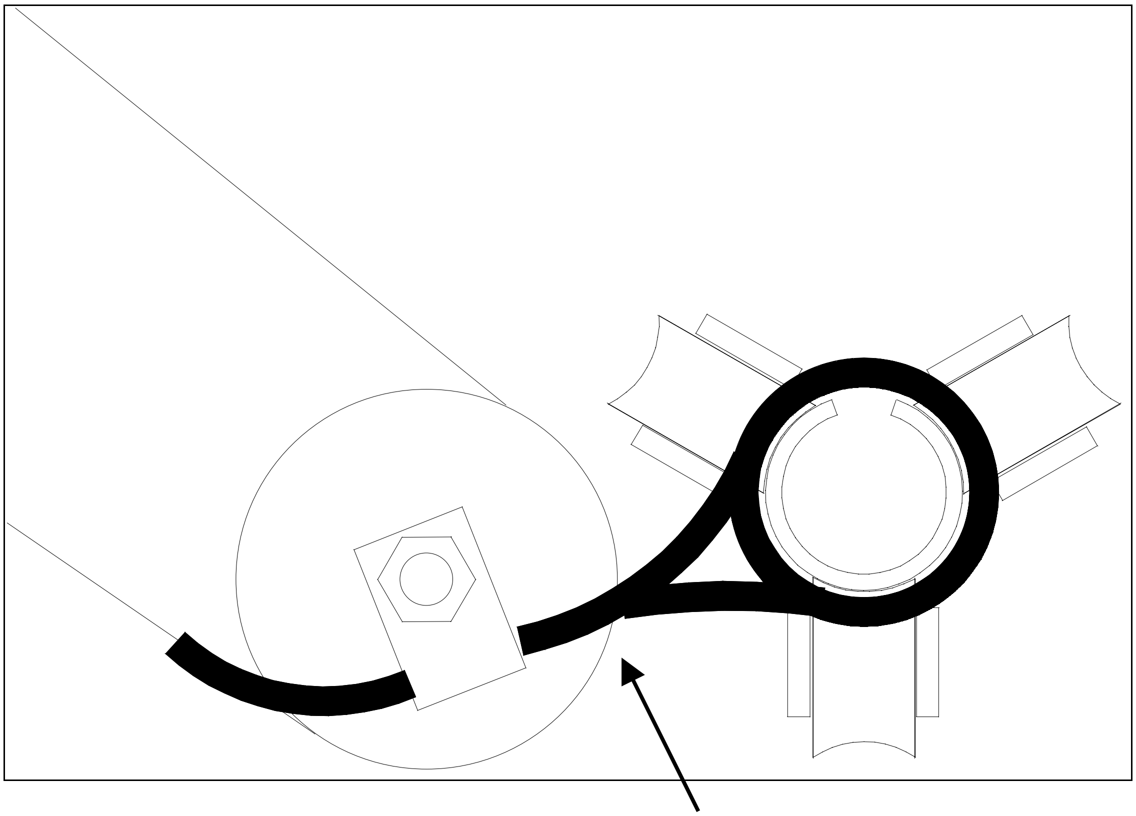
2. Supply sufficient cooling water – at least 4 USG/minute and preferably over 5 USG/minute. The coolant must be <u>very</u> clean, as the water passage around the impeder is small and easily clogged. Metal particles lodged in the impeder casing can induction heat, destroying the casing and the ferrite.

3. Position the impeder correctly (about 1/8" beyond the Vee apex). If the choice is between using a smaller impeder or meeting these criteria, then this criterion should be relaxed instead of using a smaller impeder.

4. Position the work coil so the wrap closest to the weld rolls is at 90 degrees to the mill axis and about ¼ " to ½" from the weld rolls.

5. Form the tube with as large a diameter as possible and reduce it later in the sizing section. Preferably, this tube should be formed with an outside diameter of 0.695".

6. Position the coil holder for minimal Vee length and minimal heating of the weld rolls. The Vee length should be two tube diameters or shorter. The set-up shown below positions the coil attachment part of the coil holder between the two head rolls to help minimize the Vee length:



Positioning Coil Holder between the Inside and Bottom Weld Rolls both Minimizes Vee Length and Weld Roll Heating

Process Improvements and Observations Made During a Factory Visit:

We had the opportunity to work with a manufacturer of this small diameter, thick wall tube. When we arrived at the tube mill, a maximum mill speed of about 200 feet/minute had been achieved. Above this speed, the impeder assembly would fail in only a few minutes. The following observations and adjustments were made to improve the process:

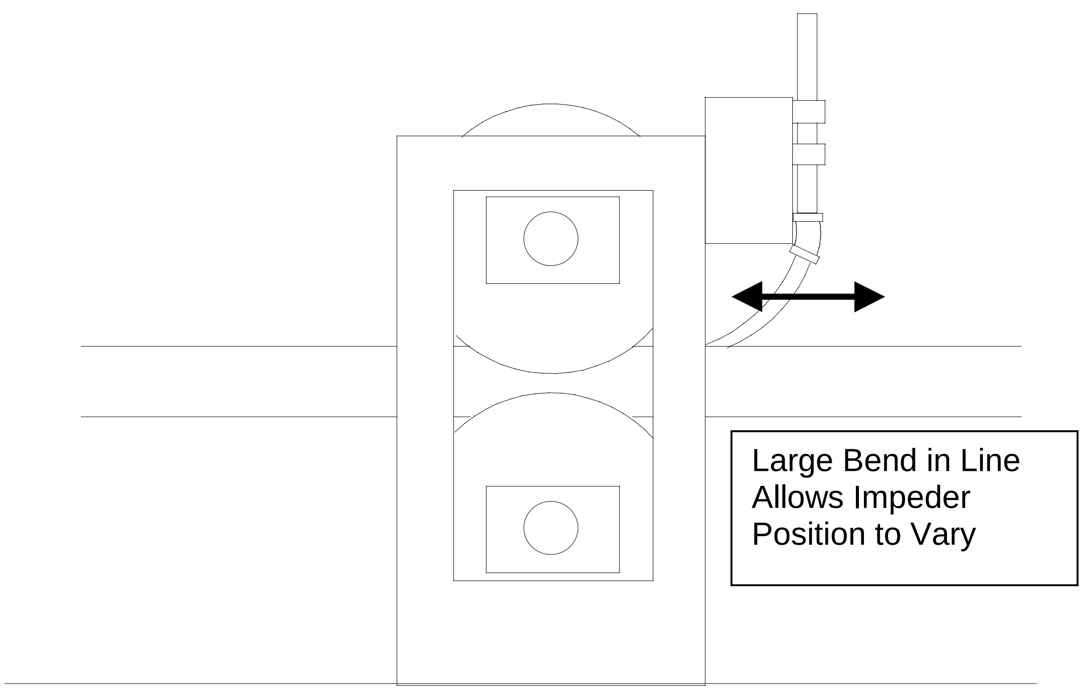
- A ¼" copper tube was being used to supply cooling water to the impeder. The flow through the coolant line was measured without the impeder in place. The flow rate was about 2 gallons per minute. The coolant line was changed to a 3/8” copper tube. This increased the flow rate to about 8 gallons per minute without the impeder.

- An encapsulated, flow through impeder was fitted to the supply line. The flow decreased to less than 3 gallons per minute. The addition of a second impeder pump in series with the first had little effect on the flow rate. A high-pressure impeder pump was ordered but could not be received in time to use in these trials. The coolant flow rate was deemed unacceptable for this impeder.

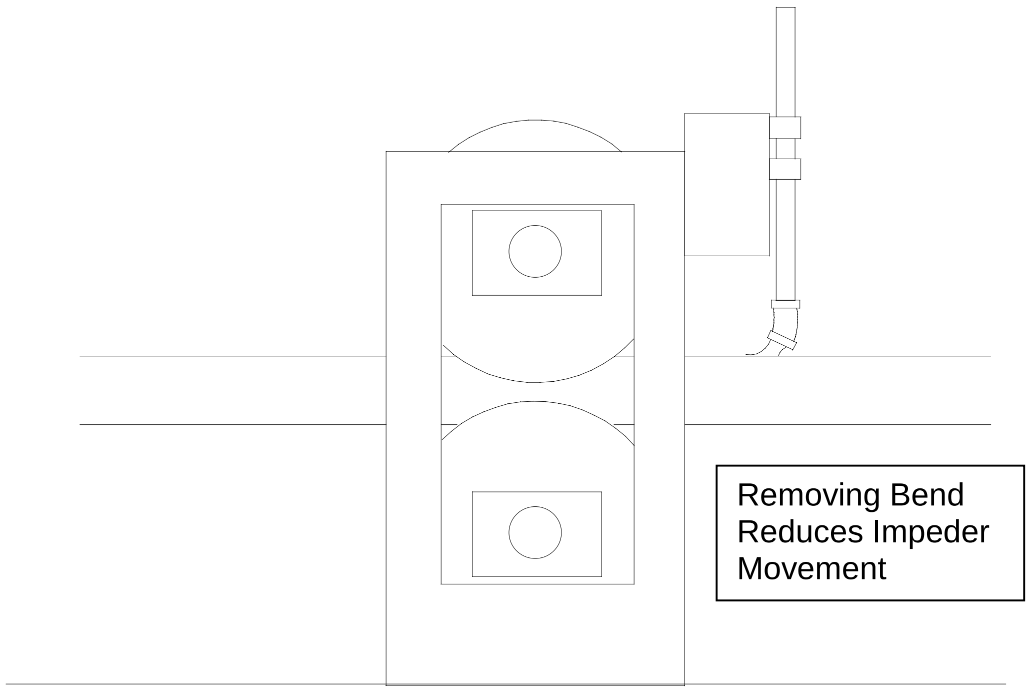
- A 12 mm exposed end impeder was fitted to the water supply line. The coolant flow through the impeder was over 5 gallons per minute. This was deemed acceptable for the trials. The 3/8” water fittings supplied with the impeder were ground to a smaller diameter. This was necessary to insure the impeder could move freely inside the tube with no binding.

- The mill coolant used for impeder cooling was not very clean and contained many fine particles. These particles can clog the passage between the impeder’s ferrite and its shell. A test was made to determine how long it would take to clog the cooling passages. The cooling supply was connected to a new impeder and the coolant flow rate was measured every 10 minutes. The water flow decreased by about 35% in a period of 30 minutes due to particles clogging the impeder’s cooling passage.

- The copper coolant line was clamped to the top of one of the mill stands and was led into the tube as shown below:



The large radius bend in the copper tube allowed the copper tube to flex due to friction between the impeder shell and the tube being formed. This caused the impeder position end position to vary back and forth. To reduce this variation, the feed pipe was lowered as shown below:



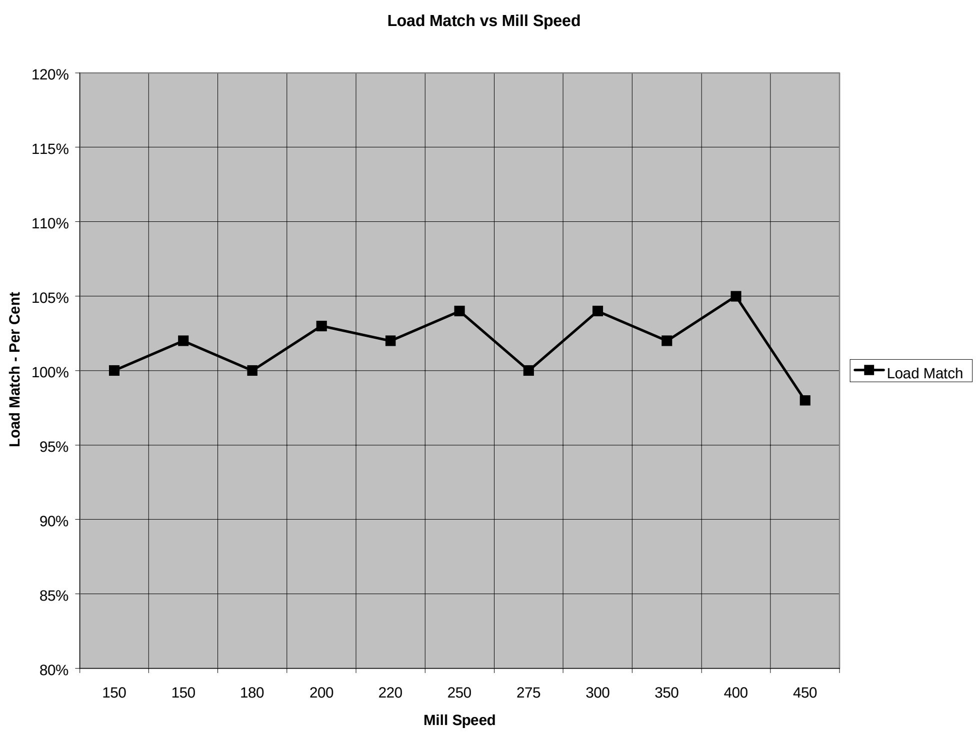
- A tubular coil with 1 1/8" inside diameter and 1 1/8" length was fitted to the welder. The coil's cooling lines were shortened by about 1 " so that the coil mount and coil could be adjusted as shown in the first figure. The first wrap of the coil was adjusted so that it was about 3/8" from the squeeze rolls and was at right angles to the mill axis. The resulting weld Vee was 1 ¼" long and 0.078 wide at the edge of the coil.

Results Obtained:

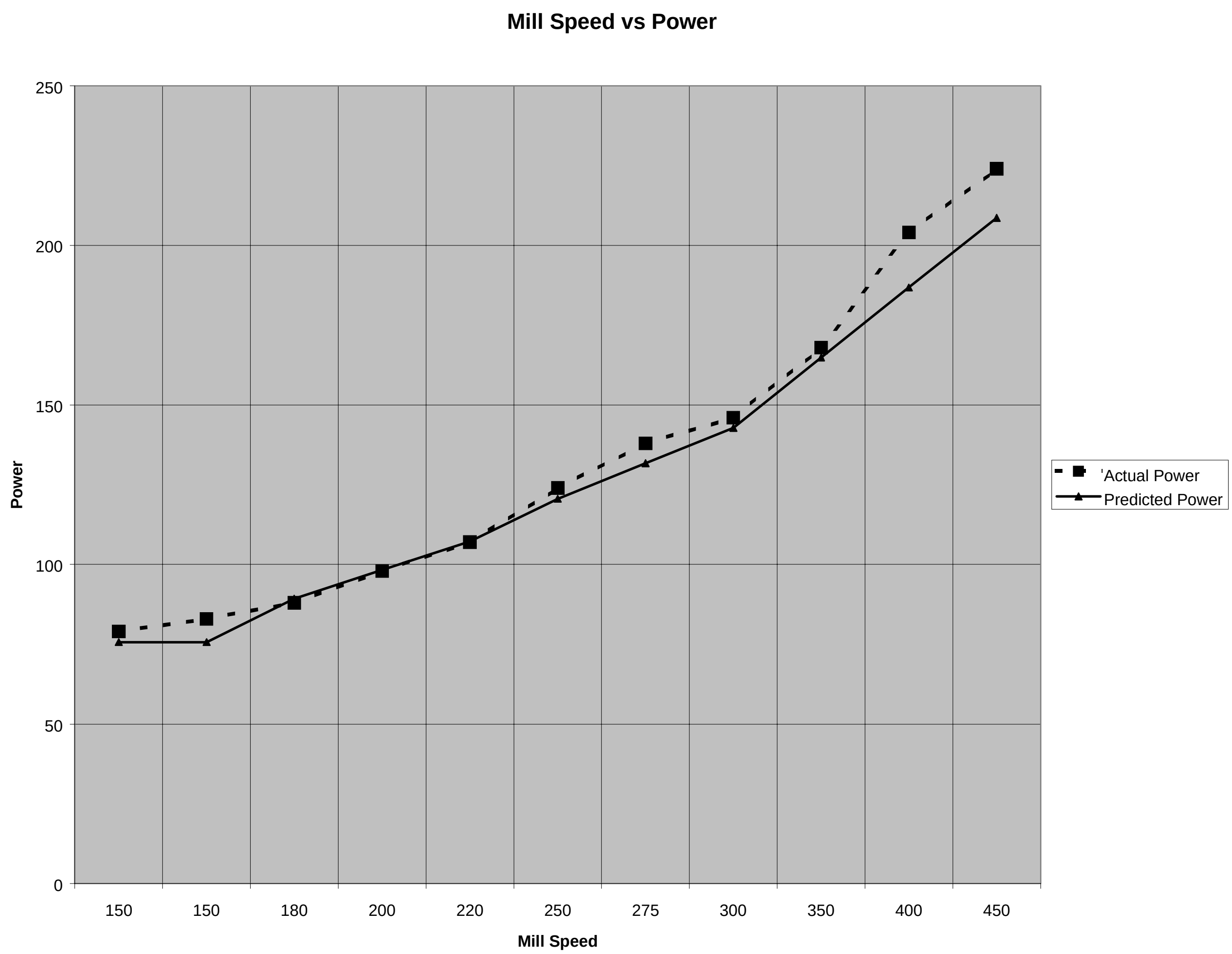
After completing the improvements outlined above, several runs of tubing were made, steadily increasing the mill speed from 150 feet per minute to 450 feet per minute. Welder data was taken at each mill speed and is shown in the table below:

Speed (Ft/Min)	Power (kW)	Frequency (kHz)	Voltage (Volts)	Current (Amps)	Match (100% = Matched)
150	79	404	250	300	100%
150	83	396	250	315	102%
180	88	396	275	323	100%
200	93	396	283	330	103%
220	107	396	300	353	102%
250	124	400	325	375	104%
275	138	404	338	405	100%
300	146	400	350	405	104%
350	188	400	375	443	102%
400	204	400	418	480	105%
450	224	400	418	510	98%

Load Match Percentage shown in the data table is plotted in the figure below:



The weld power data in the table above was compared to Thermatool's best rate predictions. The result of this analysis is shown in the graph below:



The two graphs above allow us to make the following observations:

- The welder is operating very well. The Load Match is within 5% of “perfect” so that full power is available for welding this tube.
- There is no sign of impeder saturation. This would exhibit itself as a sharp increase in the match percentage above the power level at which saturation occurred. The power requirement would also be well above that predicted.

- The maximum welding speed for this product should be above 500 feet per minute with the 300 kW welder.

Final Observations:

During the trials the impeder was "lost" twice. Initially, the impeder was adjusted so that its end was about ¼" beyond the weld point. After the mill was stopped and then restarted, the impeder's ferrite was pulled from its shell. Examination of the shell assembly indicated that the wire holding the ferrite in the shell was snapped. This was attributed to the ferrite becoming trapped by the weld bead inside the tube. The impeder was repositioned so that the end of the ferrite was at the weld point.

The second time the ferrite was lost examination of the shell assembly showed that the wire holding the ferrite had burnt. Further examination showed that a piece of rag had become lodged in the top of the shell assembly, plugging the flow of coolant.

Conclusions

The welder performed very well with the mill set-up achieved at the start of the trials. The tubular coil should be used to make this size tube. It should be noted that Thermatool's normal recommendation is to use a banded work coil. This coil works very well with the majority of 0.675 product, most of which has a diameter to thickness ratio well above 10. However for this size tube, an excellent load match can be achieved with the tubular coil and it is easier to adjust. The ultimate practical weld rate for this tube on the particular mill employed should be above 500 feet per minute.

The best set-up used during the trials consisted of an exposed ferrite impeder, 12 mm diameter, positioned so that its tip was at the weld point. Cooling flow through the impeder was about 5 USgpm. A tubular coil, 1 1/8" inside diameter and 1 1/8" long, was positioned for a Vee length of 1 ¼". This placed its leading edge about 3/8" from the weld rolls. The coil was adjusted so the wrap closest to the weld rolls completely straddled the weld Vee and was at right angles to the mill axis. The Vee width at the edge of the coil was 0.078 inches, which makes the Vee angle about 3.6 degrees.

Recommendations

The results stated above were achieved in a single day of tests. Further improvements could have been made if more time had been available. Some recommendations for additional improvements are:

- A high-pressure pump could be fitted to the impeder coolant supply. Ideally, the pump would allow a ¼" copper coolant line without sacrificing coolant flow. When higher flow rates can be achieved (above 5 Usgpm), the encapsulated, flow through impeder could be tried and the data compared to that for the exposed end impeder.

- Better filtering of the coolant flow could extend the life of the impeder by preventing clogging.

- A flow meter in the impeder coolant line would aid in determining a good mill set-up. The impeder flow should always be above 4 USgpm and preferably above 5 USgpm.

- The device used to clamp the impeder coolant line to the mill could be improved. It should provide sufficient stiffness so the impeder's end point remains stationary. It should have a "screw type" adjustment to allow accurate positioning of the impeder's end-point.

- Mill set-up needs to focus on eliminating any "peaking" of the tube edges in the weld area. Peaking of the edges contributes to the inside weld bead, which restricts the impeder.

- The weld rolls used to conduct these trials were made from tool steel. Using ceramic rolls would allow the coil to be positioned closer to the weld rolls. This would further reduce the Vee length. If ceramic rolls prove impractical, weld rolls of Armco Bronze could be tried.