John Inge Asperheim, Bjørnar Grande, ELVA Induksjon a.s

Temperature Evaluation of Weld Vee Geometry and Performance

Abstract

The heat affected zone (HAZ) in a medium– and thick-wall tube is shaped like an hourglass. This can give overheated corners and a cold center in the tube wall, which limits weld speed. A parameter study of the influence of Vee angle, spring back, weld speed and frequency is carried out.

Two-dimensional, coupled electromagnetic and thermal FEM analyses give the temperature distributions in the cross-section of the weld point. The results are presented as isothermal lines at the weld point.

Introduction

In recent years there has been an increasing desire for induction welding of big diameter pipe with increased wall thickness. The tube and pipe market has also moved towards production of smaller diameters with heavier walls than before.

This need and desire for welding thick-wall tube & pipe, at a greater throughput, may result in a typical welding problem. A cold (paste) weld condition near the cross-sectional center of the pipe can limit maximum speed, even if the mill has additional capacity and the welder additional power.

If the temperature differential in the weld zone is excessive and the operator attempts to compensate with more power, the edges of the strip can be significantly overheated and the weld quality can deteriorate. Overheated edges can cause molten material to drop onto the impeder, reducing impeder lifetime, performance and, in the end, weld quality. This situation is especially a problem with heavy wall, small diameter tube and pipe. It is a condition with the greatest need for impeder cross-section, but also on in which space is severely limited and the vertical distance between weld Vee and impeder is short.

To find a solution to this weld problem, or at least reduce it, we study parameters influencing the temperature distribution across the weld. In our first paper [1] we examined both development of temperature distribution in the x – y plane between coil and weld point (see figure 1) and the final distribution at the apex. In this paper we focus on the last stage and present isothermal lines for the final weld (before cooling takes place). The parameters involved in this study are Vee angle, weld speed and frequency. In addition, we investigate the impact of spring back for one given set of these three parameters.

Description of the model

An analytical approach to a solution of the problem is complicated. This is due to the three-dimensional nature of the electromagnetic field distribution for the tube welding setup. Computer aided numerical calculations based on a simplified two-dimensional model give us the capability of studying the problem. Calculations are carried out with the commercially available software Flux 2D. Assumptions made in the 2D model must be kept in mind when the results are analyzed.

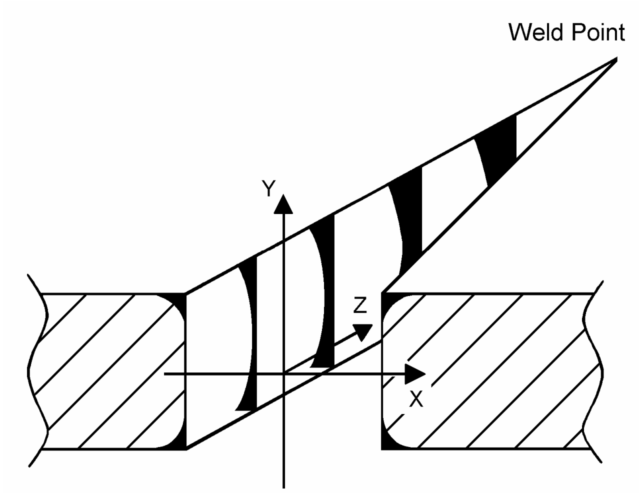

***Figure 1. Weld Vee geometry with co-ordinate axis**.*

The use of a 2D model can be justified, according to the following assumptions (a more thorough discussion on this can be found in [1]):

- The Vee current's main component is in direction of the weld point (z direction); see figure 1.
- The model can be limited to a few thermal penetration depths into the tube wall (x direction) and the tube's curvature can be neglected.
- The Vee walls are parallel during the calculation
- The impeder has no influence on the local field and current distribution in the Vee.

These simplifications result in symmetric current distributions on both sides of the tube wall centerline (x axis) and the vertical centerline in the weld Vee (y axis). Hence, the calculation domain can be reduced to one quarter of the Vee cross-section (see figure 2). Results are presented in this paper in figures displaying only one quarter of the actual geometry.

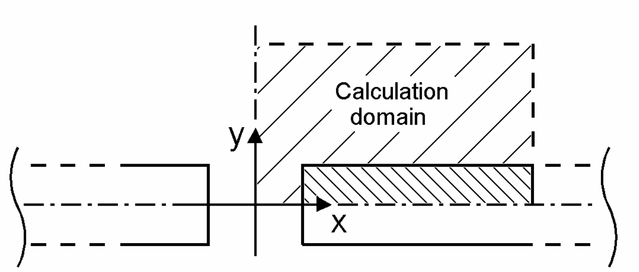

Figure 2. Cross-section of weld Vee

The mechanical setup of a tube welding line will determine if the movement of the strip edges towards each other is linear or not. We have concentrated our work on a setup where the movement is linear, but also looked at a phenomenon called spring back, shown in figure 3. For numerical reasons the movement is stopped when the distance between the tube wall and the symmetry axis is at 1/25 of the wall thickness.

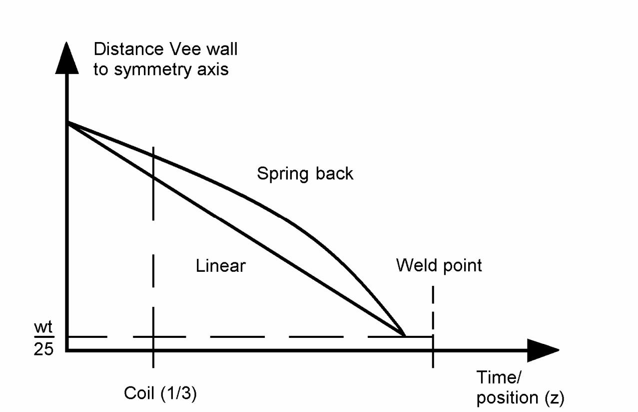

Figure 3. Distance between Vee wall and symmetry axis vs. time.

Material properties

For metal strip material in our calculations we have used low-carbon steel, one of the most common materials in tube and pipe production. Low carbon steel has highly non-linear material properties. Saturation curves and rapid changes in properties at Curie temperature present a considerable problem for numerical calculations. These changes in material properties as a function of temperature have to be smoothened somewhat.

Specific heat is an example of this. At Curie temperature the material goes through a phase transformation that consumes energy, represented by a Gaussian distribution. Melting steel requires a lot of energy. In reality, this takes place in a short temperature interval. We have equaled this by another Gaussian distribution; see figure 4. As a consequence, the temperature continues to rise slowly through this interval, as opposed to being more or less constant until enough energy is absorbed to melt the steel. Using this approximation, however, makes it easier to determine how far the melting has proceeded. Temperatures above melting temperature have little practical meaning since the metal in this case will drop onto the impeder, or be thrown away by the current forces. In any case this would alter the geometry of the strip edge corners, which is not possible to simulate with this software.

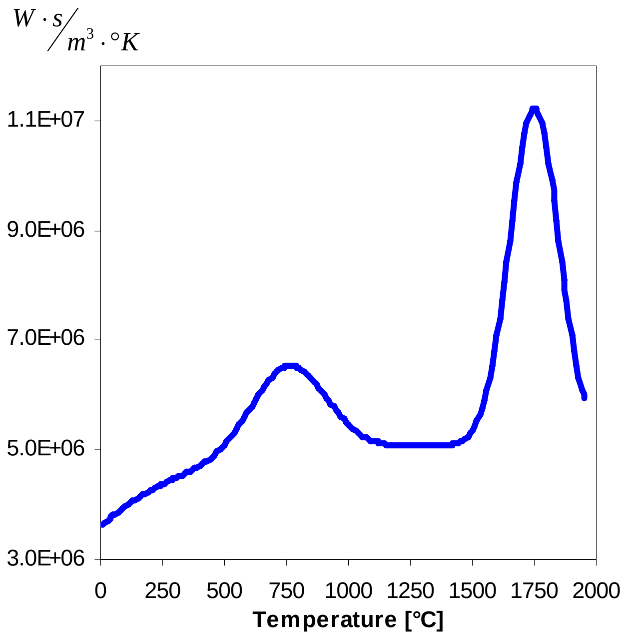

Figure 4. Specific heat vs. temperature

Results

The minimum temperature required in the cross-sectional center of the tube, to avoid cold weld condition, is a function of the applied weld roll pressure. To compare the different temperature distributions, we must have a reference point. In this case, we use temperature of 1250º C in the center point (x=y=0). The current is tuned in order to get the required reference temperature. Wall thickness is 12.7 mm (0.5") in all simulations.

Simulations are carried out for three Vee angles, two mill speeds and three frequencies. Table 1 shows the calculations performed (x). In addition, one setup with 200 kHz, 14.6 m/min and 3° Vee angle with spring back has been investigated.

Table 1. Simulation overview

	100 kHz		200 kHz			300 kHz	
m/min	3°	6°	3°	4.5°	6°	3°	6°
14.6	x	x	x	x	x	x	x
29.2	x		x		x	x	

We present a majority of the results as isothermal lines at the weld point. Throughout the paper, we use the temperatures at lines one through nine as listed in Table 2. The temperature will not rise above the melting temperature until melting is completed. Melting alters the geometry of the tube wall and consequently influences the power distribution. The model's limitation must be kept in mind when studying the results. It is our intention to describe the parameters' influences on the temperature distribution, and not what occurs during melting.

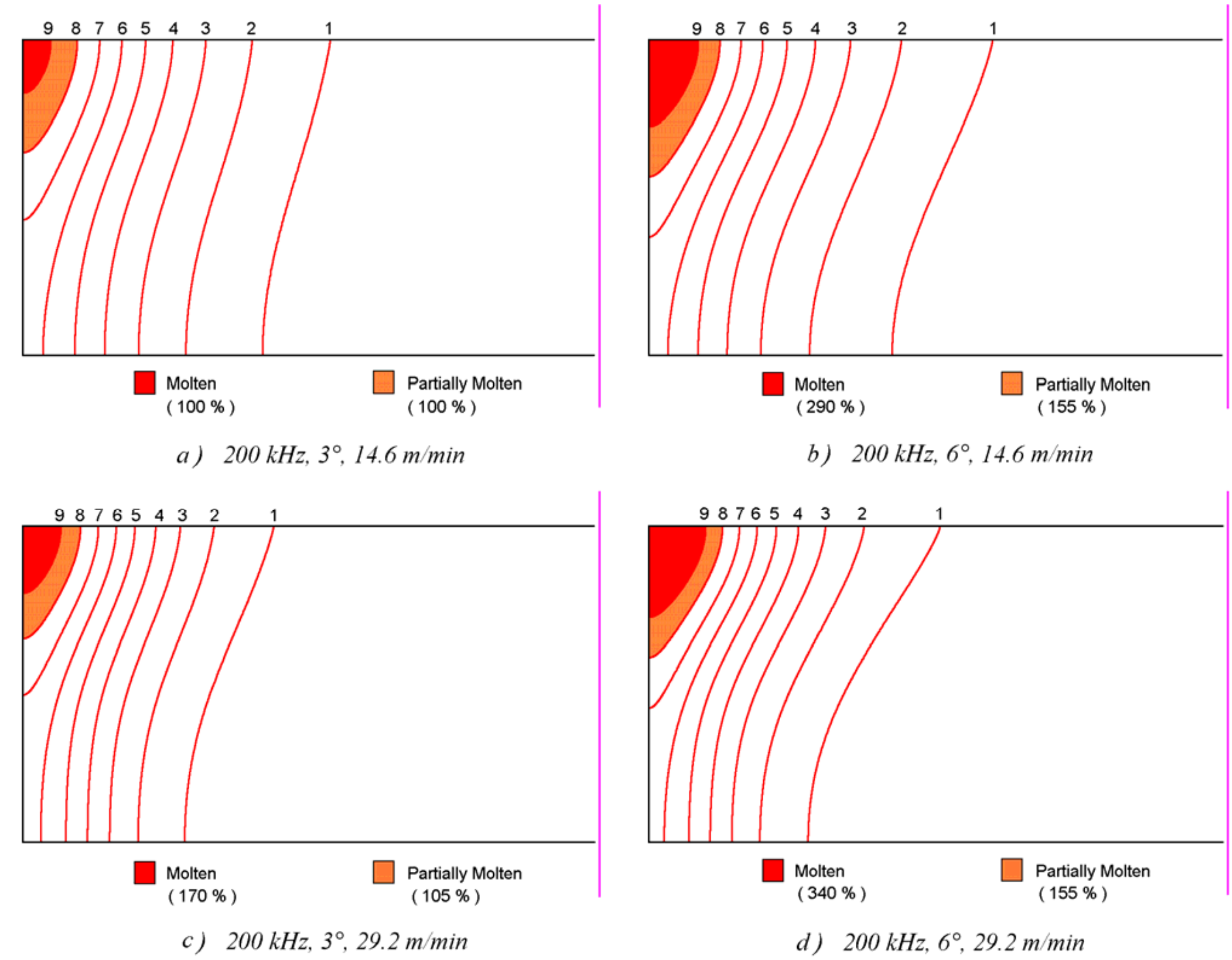

Figure 5. Isothermal lines at the weld point; 200 kHz

Table 2. Isothermal line values

	1	2	3	4	5	6	7	8	9
°C	325	500	675	850	1025	1200	1375	1550	1725
°F	617	932	1247	1562	1877	2192	2507	2822	3137

Table 3. Simulation results

Angle	Mill speed	$\delta_{th90\%}$	Vee power	Vee voltage
°	m/min	mm	%	%
100 kHz				
3	14.6	0.85	108	66
6	14.6	0.83	120	98
3	29.2	0.71	170	82
200 kHz				
3	14.6	0.70	100	100
3 SB	14.6	0.69	105	115
4.5	14.6	0.68	107	128
6	14.6	0.67	112	153
3	29.2	0.59	157	121
6	29.2	0.56	179	192
300 kHz				
3	14.6	0.63	96	128
6	14.6	0.59	109	201
3	29.2	0.52	152	160

To compare the setups, we have calculated the cross-sections of molten and partly molten material in the isothermal plots. In each figure we have indicated the sizes in percentage of the cross-sections for a reference setup (200 kHz, 3° Vee angle and 14.6 m/min mill speed).

Figure 5 shows the isothermal plots of upper half the tube wall cross-section for different 200 kHz setups. An increase in Vee angle from 3° to 6° increases the cross-section and amount of molten material (above 1725 °C) about three times at low speed and two times at high speed. The amount of partly molten material (above 1550 °C) increases approximately 50 % for both mill speeds.

Temperature distribution along the tube wall centerline (x-axis) is mainly affected by speed and, hence, heating time. An increase in angle and speed results in more heating of the tube wall corners. The result is a more pronounced hourglass shaped heated zone. This effect is most evident in figure 5d, with the combination of high-speed and wide angle.

Figure 6 displays the temperature distributions for 100 and 300 kHz. There are no big differences in cross-sections regarding partly molten material for these two frequencies. There is, however, a distinct difference in the amount of molten material.

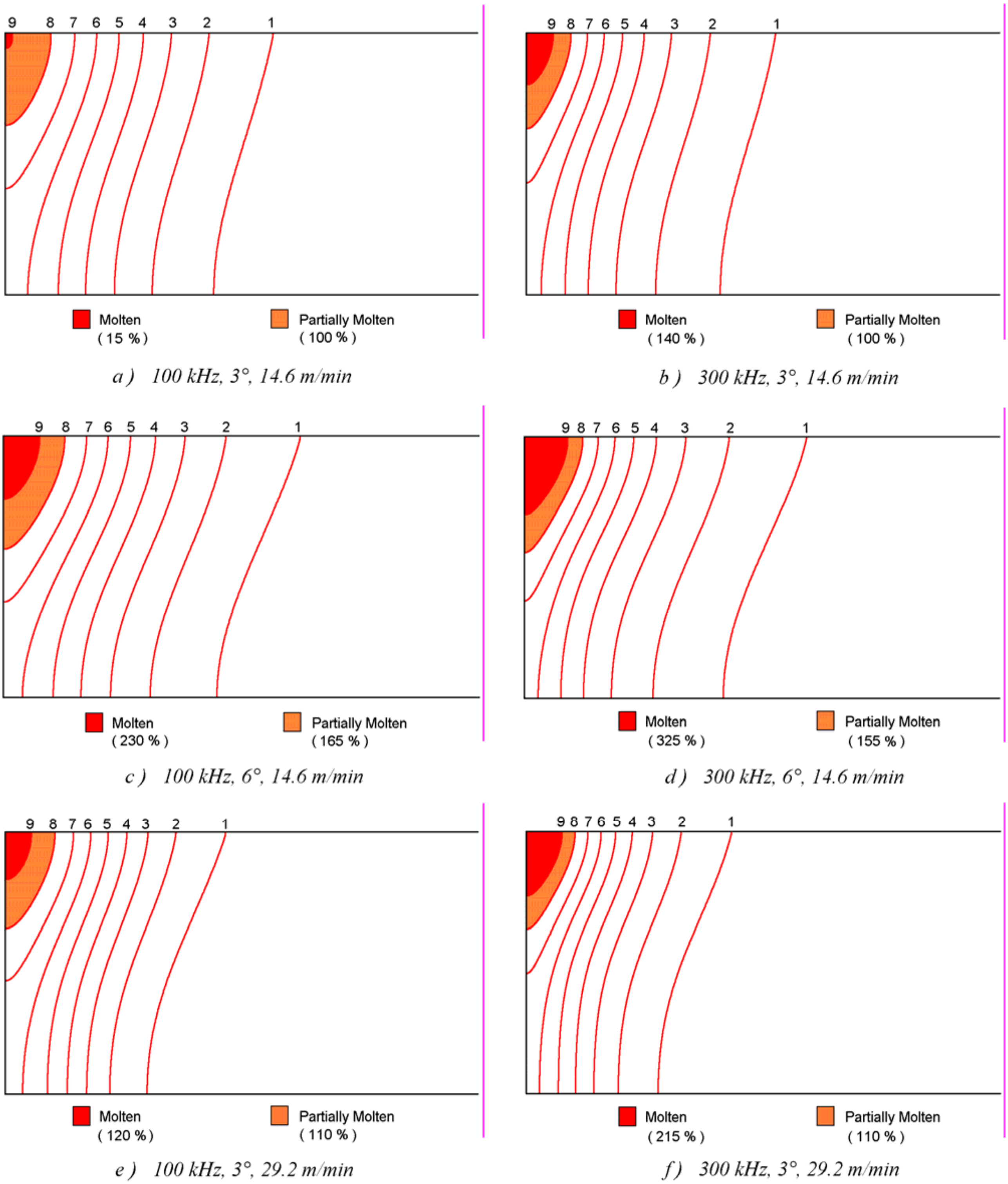

Figure 6. Isothermal distributions, comparison between 100 and 300 kHz

Focusing on the increase in Vee angle, we see that there is a significant change in the quantity of molten material, with an increase of approximately 15 and 2 times for 100 and 300 kHz, respectively.

When comparing figures 6c and 6b, we see that twice the Vee angle has a greater impact on both molten and partly molten cross-sections than three times the frequency.

The results show that the 3°, 29.2 m/min setup gives less temperature differential in the weld zone than 6° and 14.6 m/min. In figures 7c and 5c, we see that even a 1.5° reduction in Vee angle gives a better result.

We have investigated the effect of Vee angle and spring back on the temperature distribution in more detail at 200 kHz; see figure 7. The position of the tube wall as a function of time and position is illustrated in figure 3. The Vee shape in the spring back case is based on measurements on a mill running similar tube dimensions. At the beginning of the calculation, the distance between strip edge and symmetry axis is equal to that of a linear Vee with 3° angle.

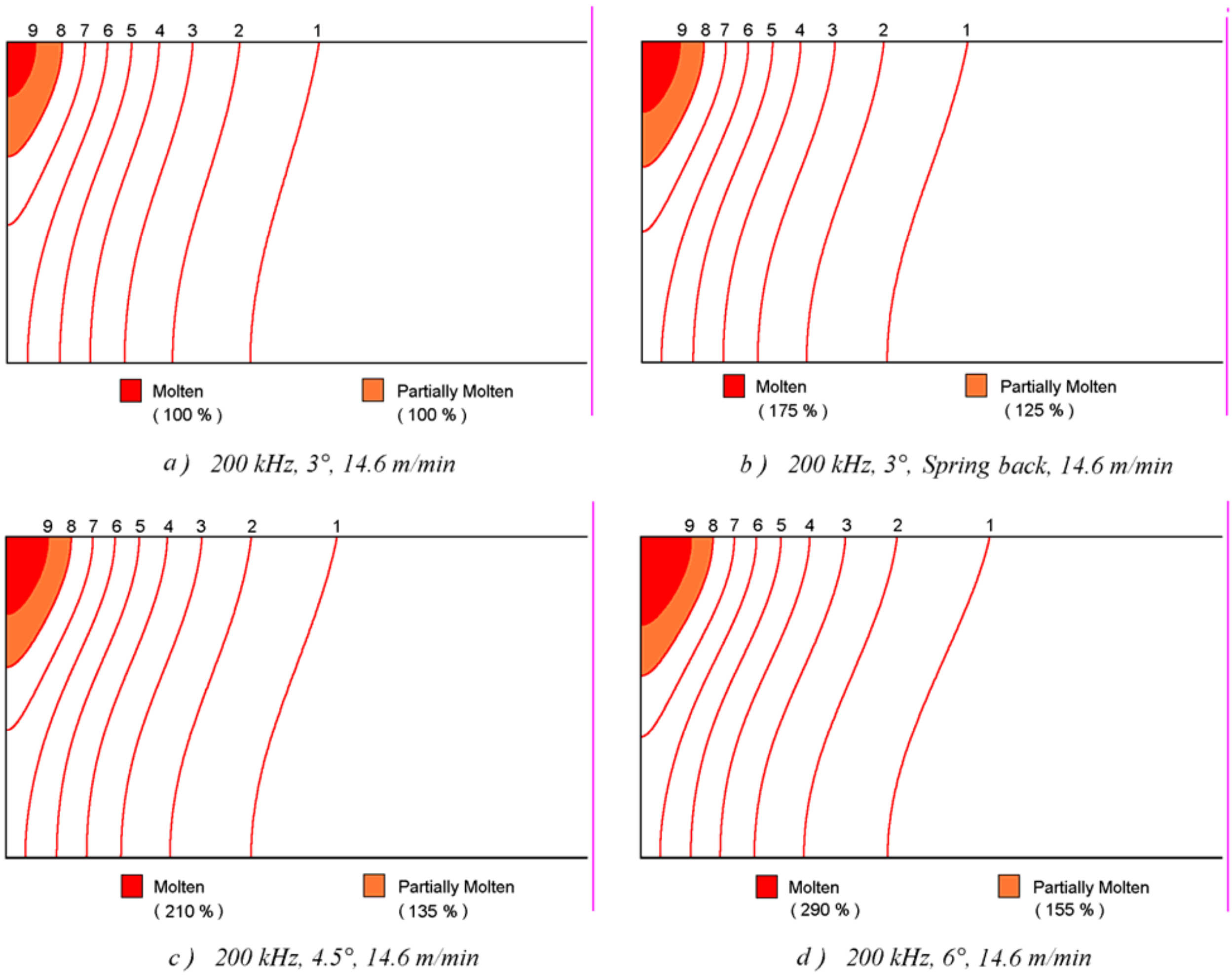

Figure 7. Isothermal plots, effects of Vee angle and spring back at 200 kHz

As expected, the quantity of molten and partially molten material increases with Vee angle. Figure 8 shows that there is almost a linear relationship between melting and angle, and that spring back in this case equals an angle of 4° for a linear Vee.

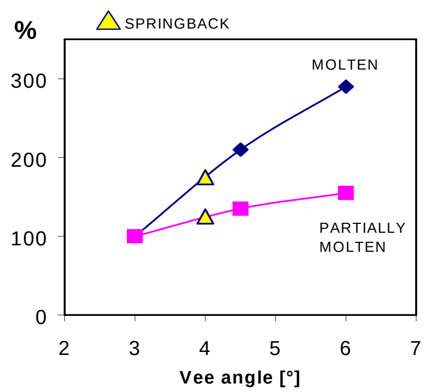

Figure 8. Melting vs. Vee angle

In [1] we investigated the temperature distribution from the strip edge center and into the tube wall (x-direction). We referred to a heated zone, defined as the width of a region with temperature within 90-100 % of the surface temperature. The measured widths ($\delta_{th90\%}$) for all setups are listed in table 3.

The temperature decreases faster in x-direction at higher frequencies, indicating a narrower heated zone. Energy input to the weld zone, however, is not correspondingly low. Overheated strip edge corners increase the energy consumption at higher frequency.

$\delta_{th90\%}$ values are somewhat lower for 6° Vee angle than 3°. In contrast to the result of increasing frequency, an increased angle requires higher energy input. This is a consequence of more overheated corners and is evident by the heated zone’s more pronounced hourglass shape.

Assuming constant Vee-Welder power ratio, a reduced Vee angle from 6° to 3° will reduce power consumption with 12%. This will allow an 18-20% increase in mill speed for the same welder, due to the relationship between power and mill speed. An additional benefit is a better temperature distribution in the Vee, with less overheating of the corners.

A well-known argument against small angles is increased problems with flash-over between the strip edges. This concern comes from experience with high frequency welders (400 kHz and above) and, often necessary, setups with wide angles. From the relative values in the Vee voltage column in table 3, it is obvious that smaller angles can be used at lower frequencies. Spring back worsens the situation, increasing voltage by 15 %.

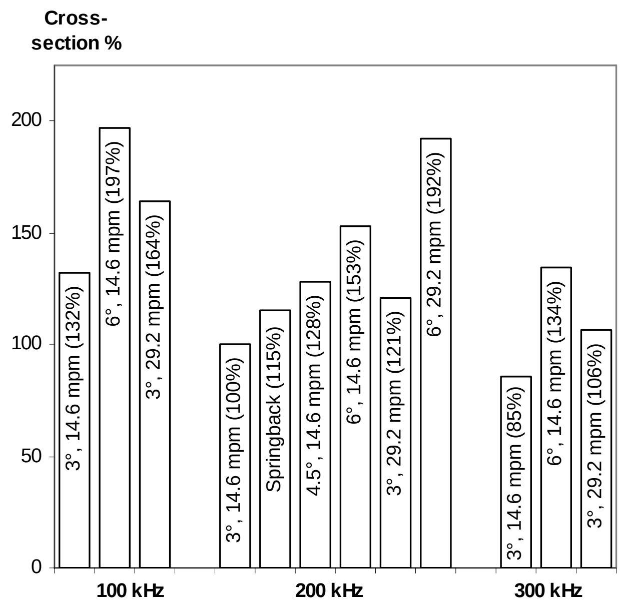

Figure 9. Impeder cross-section

The necessary impeder cross-sections are calculated on the basis of frequencies and voltages in table 3; see figure 9. Lower frequencies demand bigger impeder cross-sections for the same Vee angle and weld speed. The angle has a large influence on the required cross-section. A 100 kHz step in frequency is compensated by a 1.5 ° change in Vee angle.

The impeder cross-sections (and Vee voltages) show that the spring back setup equals an angle of 3.8° for a linear Vee, which is in good agreement with what we found for melting.

Elva Induksjon as
PO Box 760, N-3701 SKIEN
NORWAY
www.efd-induction.com
Phone: +47 35 50 60 00
Fax: +47 35 50 60 10

Conclusions

Temperature distributions calculated in this article show the importance of a small Vee angle. An excessive angle results in overheated strip edge corners and intensifies the problem with cold tube wall center. The calculations indicate an almost linear relationship between the amount of molten material and Vee angle. Furthermore, a reduced Vee angle requires less energy input and smaller impeder cross-section. By reducing the angle, one can increase the mill speed considerably. These advantages are independent of frequency.

Spring back has the same effect on the weld problem as an increased Vee angle. The real life spring back equals, approximately, a one-degree larger angle for a linear Vee. Consequently, it increases power consumption and the required impeder cross-section.

There is less temperature differential in the weld zone for low frequency. The required impeder cross-section is bigger. Thus, care must be taken when introducing lower frequency on thick-wall, small diameter tubes. Optimizing impeder position, size and cooling is vital for high-performance production. A reduced Vee angle gives less stress on the impeder and may be crucial for a high throughput at low frequency, due to limited impeder space.

The basis for this paper is an actual weld problem where the cold center of the tube wall limits speed. A small Vee angle increases the potential for higher throughput and the overall welding efficiency. For large diameter tube production, the conditions can be set for introduction of 100 kHz welder frequency. IGBT technology with a higher-power-to-volume ratio and a lower-cost-to-power ratio is then within reach.

References

[1] J.I. Asperheim, B. Grande, L. Markegård, J.E. Buser, P. Lombard, "Temperature distribution in the cross-section of the weld Vee", Tube Int., November 1998

[2] P.F. Scott, W. Smith, "The key parameters of high frequency welding", Tube Int., March 1996

[3] FLUX2D user's guide, version 7.4, CEDRAT, 1999