Better Understanding of the Upset and Flash Welding as a Solid state Joining Process

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Background (1)

- Many textbooks said that the upset welding is the typical resistance welding process. The process can be and shall be explained with the simple one-dimensional heat conduction model.
Background (2)

- However, the weld results remarkably influenced by the edge shapes of weld components.

(A) In a case of smooth (ideal) edge

(B) In a case of corn edge

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Background (3)

- The difference suggests that heat concentration near the faying interface is important to make good weld.
- This occurs the following temperature distribution.
The same concept may be applicable to understand the flash welding if the flashing stage is a preheating process to realize the heat concentration near the faying interface.
Today’s contents

1. How to remove the oxide from the joint interface
2. Required conditions to make better solid joint
3. How to realize the conditions to realize better upset welds
4. Reason why not to apply the same method of upset welding to flash welding
5. Importance of joules heating during flashing stage in flash welding
How to remove the oxide from the faying interface

Following methods can be used to remove the oxide from the faying interface:

1) Direct removal with the Reduction,
2) Removal to solid matrix with diffusion phenomena,
3) Melting and solute into molten metal of large amount,
4) Melting and ejected from the faying surface,
5) Make clean surface by the plastic flow,

The first is realized by brazing, the second is by diffusion welding, the third is fusion welding, the fifth is by solid joining (pressure welding). The forth may ne also realized by pressure welding.
Relationship between surface exposure and bond strength

After N. Bay, J of Eng, 1992

Interfacial extension $\varepsilon_i = (x-x_0)/x_0$

(1) Cu-Cu
(2) Cu-Fe
(3) Al-Al
(4) Cu-Al
(5) Cu-Ni
(6) Cu-Ag
(7) Zn-Zn

$\tau_B$ - BOND STRENGTH (N/mm²)

After N. Bay, J of Eng, 1992

AWS and RWMA, 2014-04
How to understand the results

Minimum required interfacial extension is around 2.

(a) Ideal state of joint

(b) Effective joint as a real state
Influence of surface asperity

Controlled rough surface leads better results.

After Nakamura, Sosei-to-kako, 1987
Joining model with surface asperity (1)

After Takahashi, J of JWS, 1998
Influence of surface profile on interfacial extension

There is better asperity of the surface profile to flow out.

(a) Large tip angle

(b) Small tip angle

After Takahashi, Trans of ASM, 1993
AWS and RWMA, 2014-04

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Influence of axial temperature distribution

Large gradient leads better expansion at the faying surface.

\[ H_0 = 5 \text{mm}, \ D_0 = 5 \text{mm}, \ HT500 \]

After Takahashi, Doc of MP, JWS, 1992

AWS and RWMA, 2014-04
Influence of axial temperature distribution

High center temperature condition is better to make big expansion.

(a) Outer is high

\( H_0 = 5 \text{mm}, D_0 = 5 \text{mm}, \text{HT500} \)

(b) Center is high

After Takahashi, Doc of MP, JWS, 1992

AWS and RWMA, 2014-04
Required setting condition to make better welds in pressure welding

According to Prof. Y. Takahashi,

- Increasing temperature from the base metal to the faying interface,

- Center temperature is higher then the outer part.

- Better surface asperity is necessary,
Required setting condition to make better welds in pressure welding

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How to realize these conditions in resistance heating?
Examination with a numerical simulation

After Matsuyama, SMWC XIV, 2010

@ Kin-ichi Matsuyama

AWS and RWMA, 2014-04
Influence of initial contact diameter

After Matsuyama, SMWC XIV, 2010

@ Kin-ichi Matsuyama

AWS and RWMA, 2014-04
Influence of initial contact diameter

\[ d_{\text{ini}} = \begin{align*} 
& 1.2 \text{mm} & l = 6.0 \text{kA} \\
& 2.8 \text{mm} & l = 6.0 \text{kA} \\
& 2.8 \text{mm} & l = 6.7 \text{kA} \\
\end{align*} \]

After Matsuyama, SMWC XIV, 2010

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AWS and RWMA, 2014-04
Background (2)

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Why large cross-section materials are difficult to joint with upset welding?

Similarity law cannot apply to this case.

Condition of similarity law:
- When edge width is $n$ times,
- Extension: $n$ times,
- Current density: $1/n$,
- Heating time: $n^2$ time

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AWS and RWMA, 2014-04
Why large cross-section materials are difficult to joint with upset welding?

Similarity law cannot apply to this case.

Solution is to apply an additional heating at the faying surfaces.

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Upset process with edge heated materials

(a) Start condition
(t = 0 ms)

(b) After joules heating
(t = 60 ms)
What heating energy is adequate in the flashing stage

There are two type energy.
  - One is Arc heating,
  - The other is Joules heating

However, if the heating generated only by the arcing, and all molten metal removed from the faying interface, the temperature distribution can be described as follows;

\[ T(x) = T_s e^{-\frac{vx}{k}} \]

Where, \( T_s \): Edge temperature (= mp), \( v \): Moving speed of the edge, \( x \): Distance from the edge, \( k \): Thermal diffusivity
Effect of initial temperature distribution on the temperature at the faying surface

Arc (flashing) heating alone is not recommended from view point of temperature history.

(a) Initial temperature distribution
(b) Temperature history at the faying interface during upset process
How to increase the short-circuiting ration

Solution: Low secondary voltage setting.

![Graph showing the relationship between voltage of freezing limit, occurrence ratio of each phase, and no-load secondary voltage V20 (V) for different types of welding power sources: low impedance and high impedance.](image-url)
Effect of high short-circuiting condition setting

Upset time: 5 cycles in 50 Hz

Soundness of welds by bending test (%)

No-load secondary voltage $V_{20}$ (V)

Voltage of freezing limit

$I_a$: Upset current

High short-circuiting condition

Slow cooling
Summary

- Adequate temperature distribution, which means flow stress distribution, near the faying surface leads better quality upset and flash welds as the solid state joining process.

- The setting conditions for the joining including edge profile can be predicted by a numerical simulation if correct materials properties with temperature and strain rate dependency could be supplied for the simulation.
Thank you for your attention!