Diffusion Welding

Diffusion Welding

Lesson Objectives

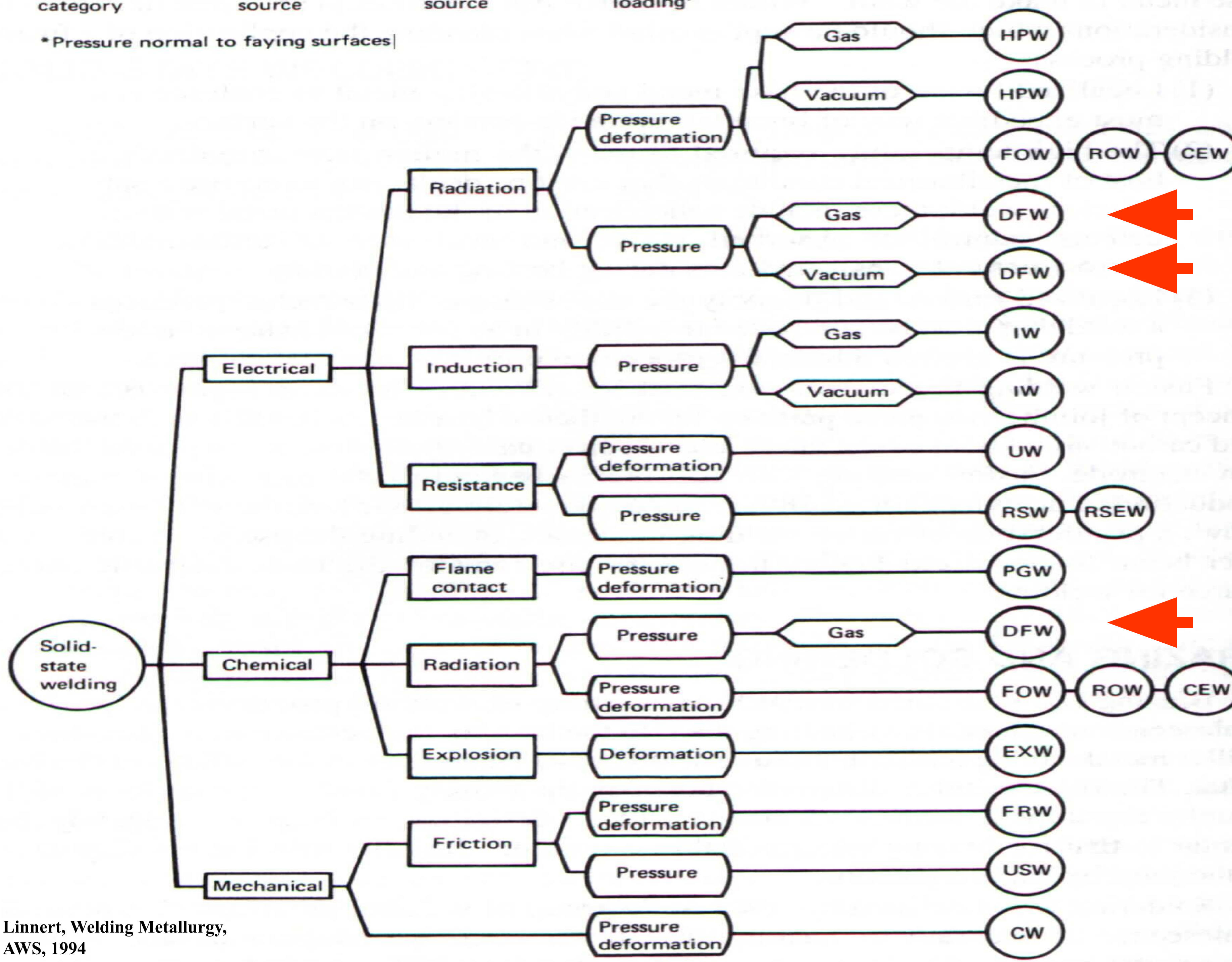
When you finish this lesson you will understand:

- Diffusion Welding Definition, Characteristics, Process & Applications
- Diffusion Coefficients & Kirkendall Effect
- Interface Interactions & Dissimilar Metals

Learning Activities

1. View Slides;
2. Read Notes,
3. Listen to lecture
4. Do on-line workbook

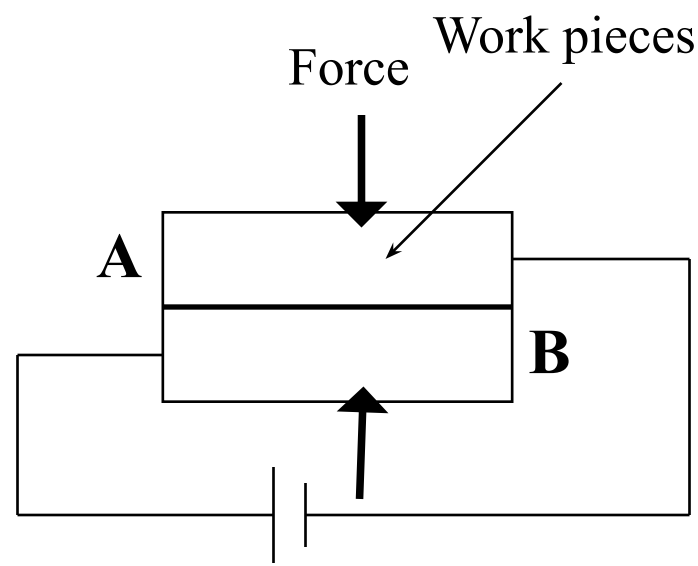
Keywords: Diffusion Welding, Diffusion Brazing, Transient Liquid Phase Bonding, Diffusion Coefficient, Kirkendall Porosity



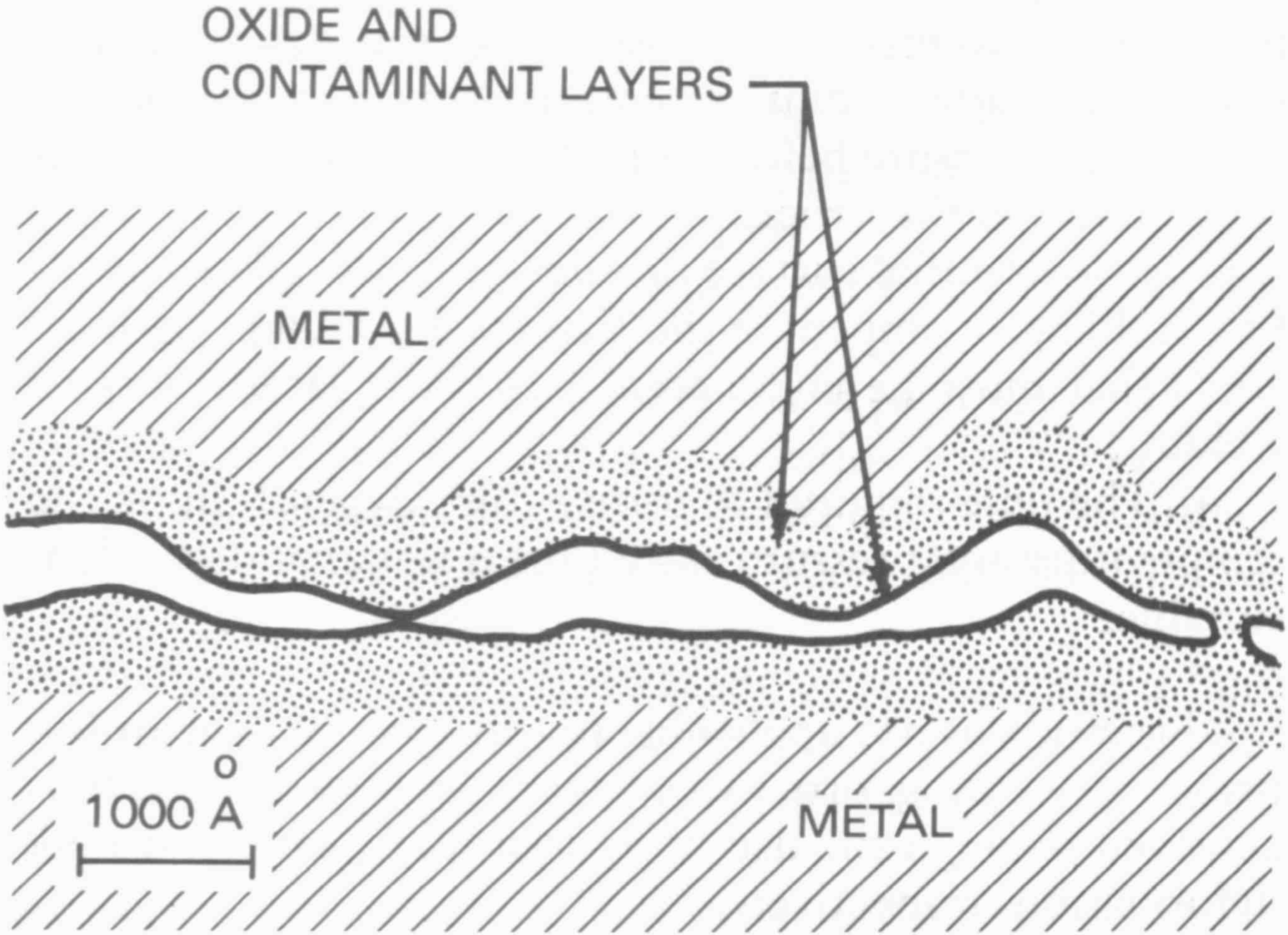
Linnert, Welding Metallurgy, AWS, 1994

Definition of Diffusion Welding

- A solid-state welding process that produces coalescence of the faying surfaces by the application of pressure at elevated temperature.
- The process does not involve macroscopic deformation, or relative motion of the workpieces.
- A solid filler metal may or may not be inserted between the faying surfaces.



Schematic representation of diffusion welding using electrical resistance for heating

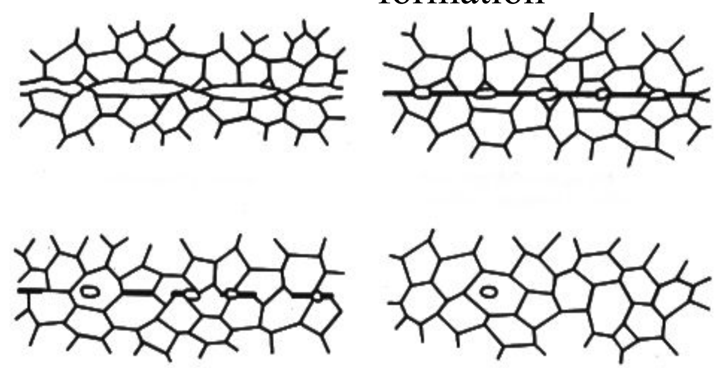

OXIDE AND
CONTAMINANT LAYERS
METAL
1000 Å
METAL

Diffusion Welding Working Principles

- 1st stage
  - deformation forming interfacial boundary.
- 2nd stage
  - Grain boundary migration and pore elimination.
- 3rd stage
  - Volume diffusion and pore elimination.

asperities come into contact.

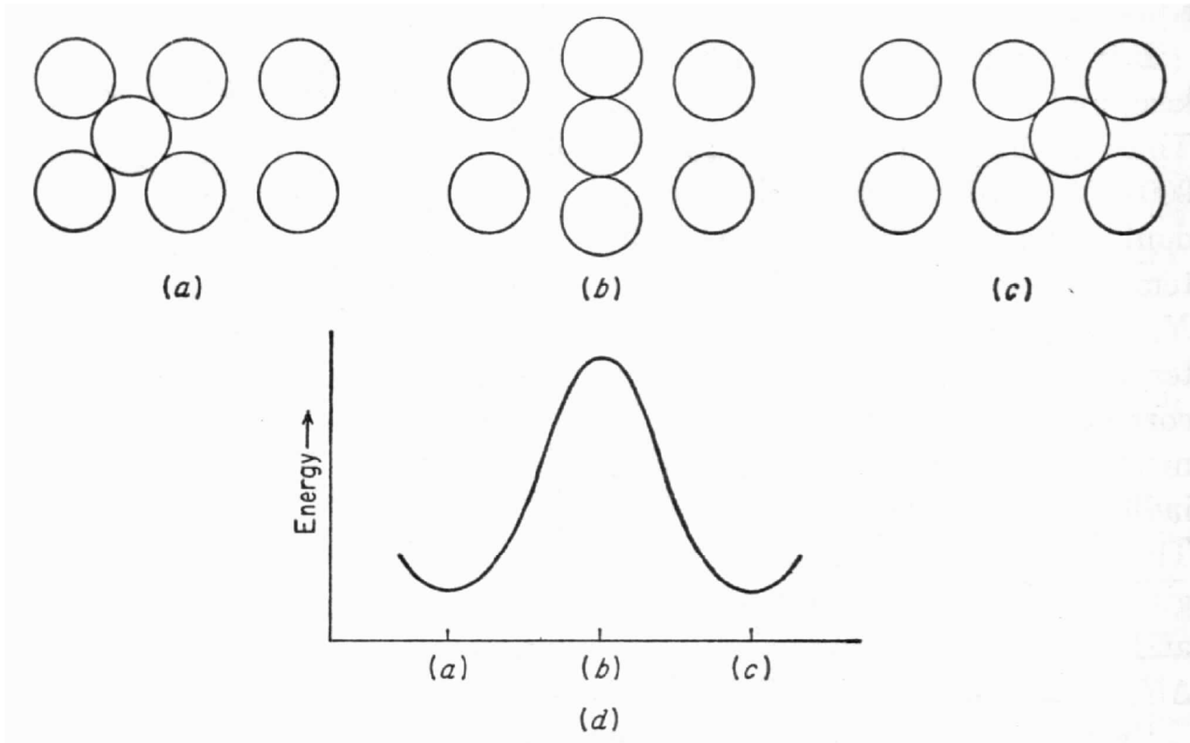
1st stage deformation and interfacial boundary formation



2nd stage grain boundary migration and pore elimination

3rd stage volume diffusion pore elimination

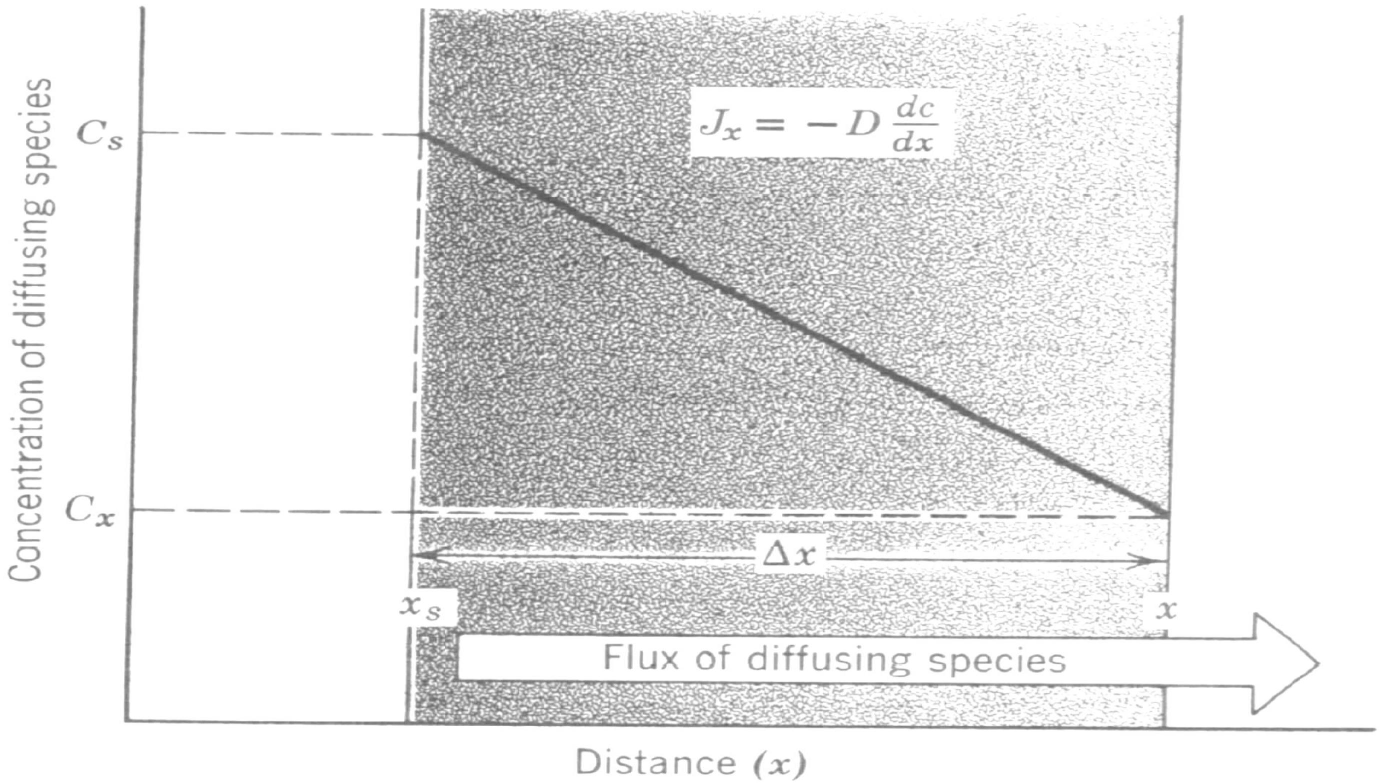
Free Energy as Atom Reversibly Moves



Factors Influencing Diffusion Welding

(Relation between Temperature and Diffusion Coefficient)

- Temperature
- $D = D_0 \, e^{-Q/KT}$
  - D = Diffusion coefficient
  - D_0 = Diffusion constant
  - Q = Activation energy
  - T = Absolute temperature
  - K = Boltzman's constant

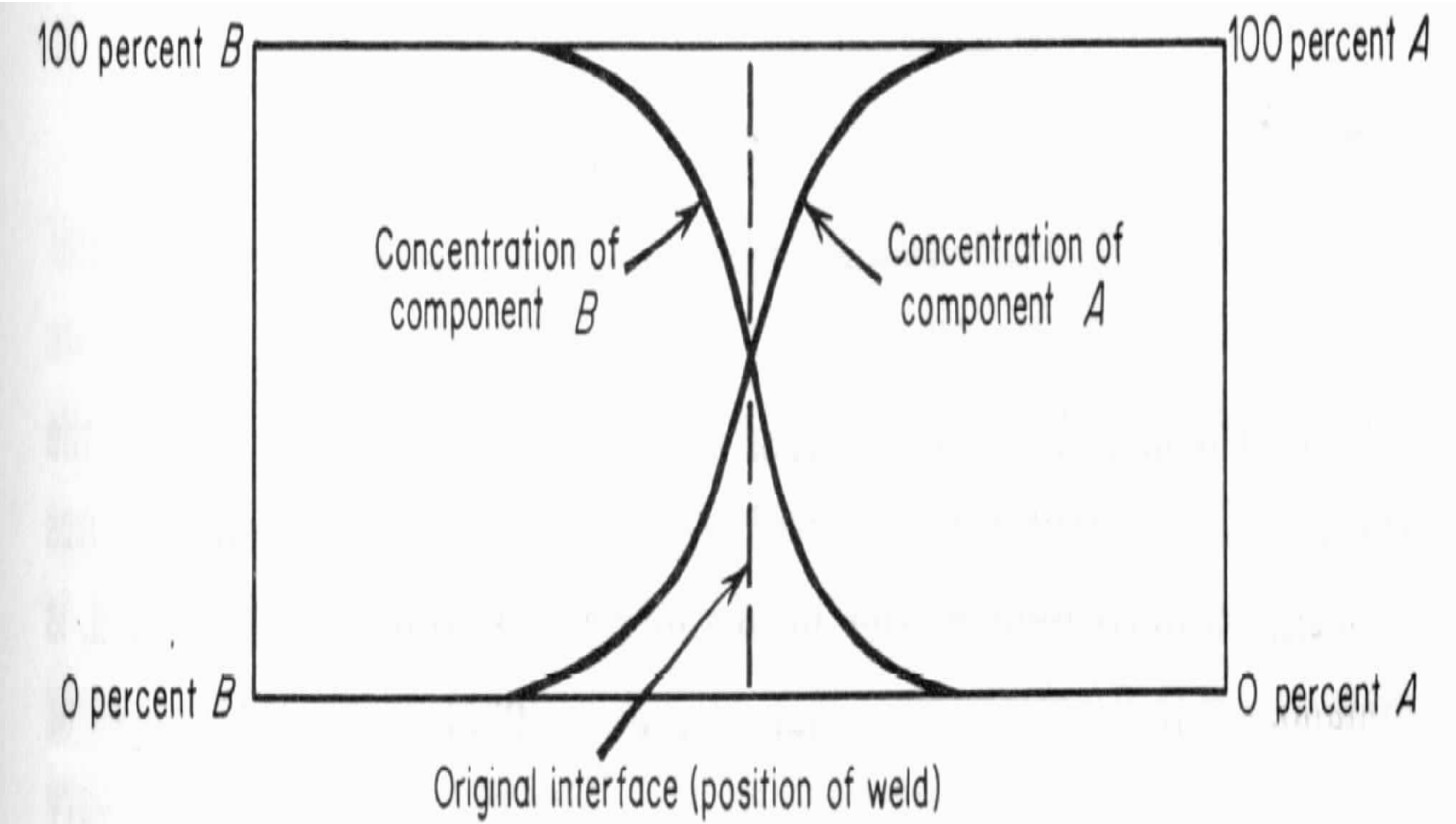


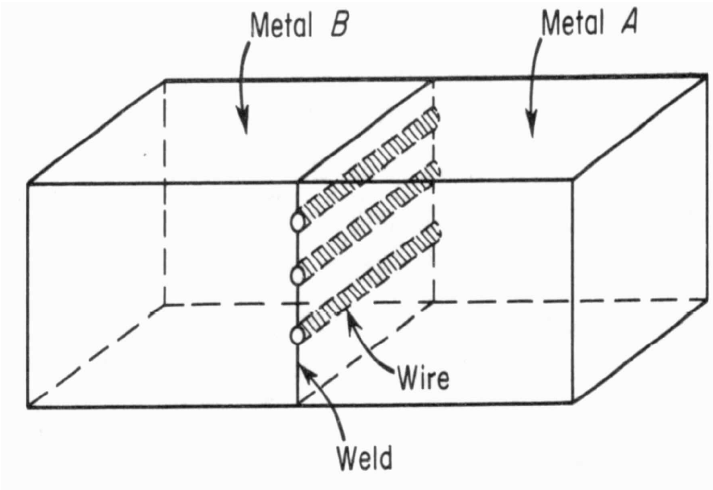
$$J_1 = -D_1 \left(\frac{dc}{dx} \right)$$

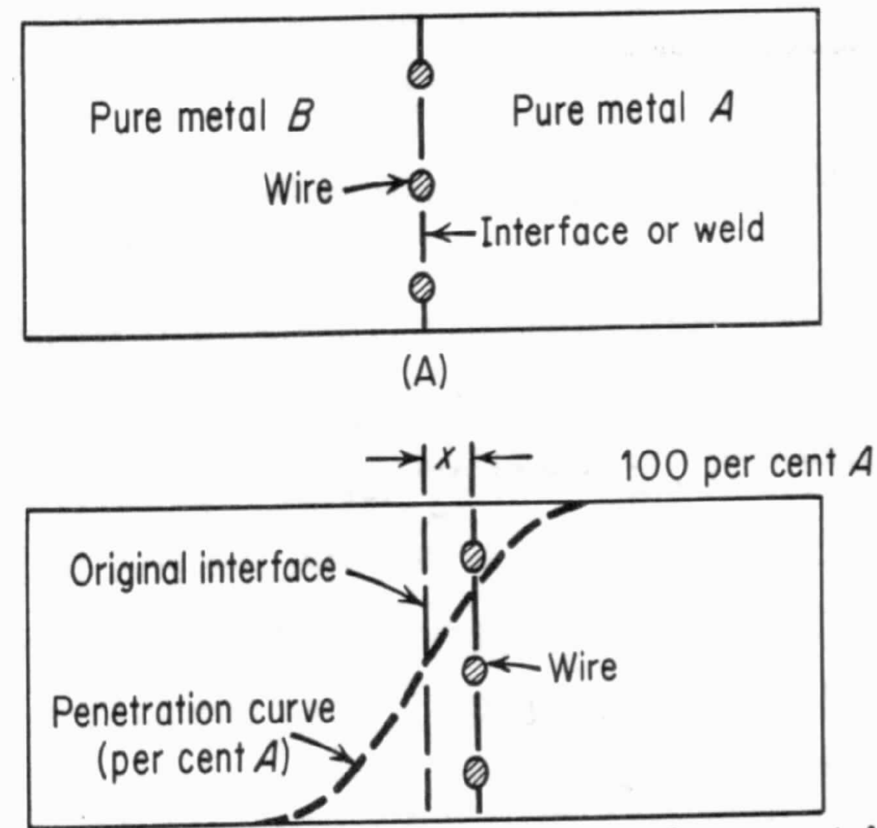
$$\frac{\text{Mass}}{L^2 t} \qquad \frac{L^2}{t} \qquad \frac{\text{Mass}/L^3}{L}$$

Factors Influencing Diffusion Welding

- Temperature (effects diffusion coefficient)
- Time
- $X = C\,(Dt)^{1/2}$ = Diffusion Length
  - X = Diffusion length
  - C = A constant
  - D = Diffusion coefficient (see previous slide)
  - t =Time
- Pressure

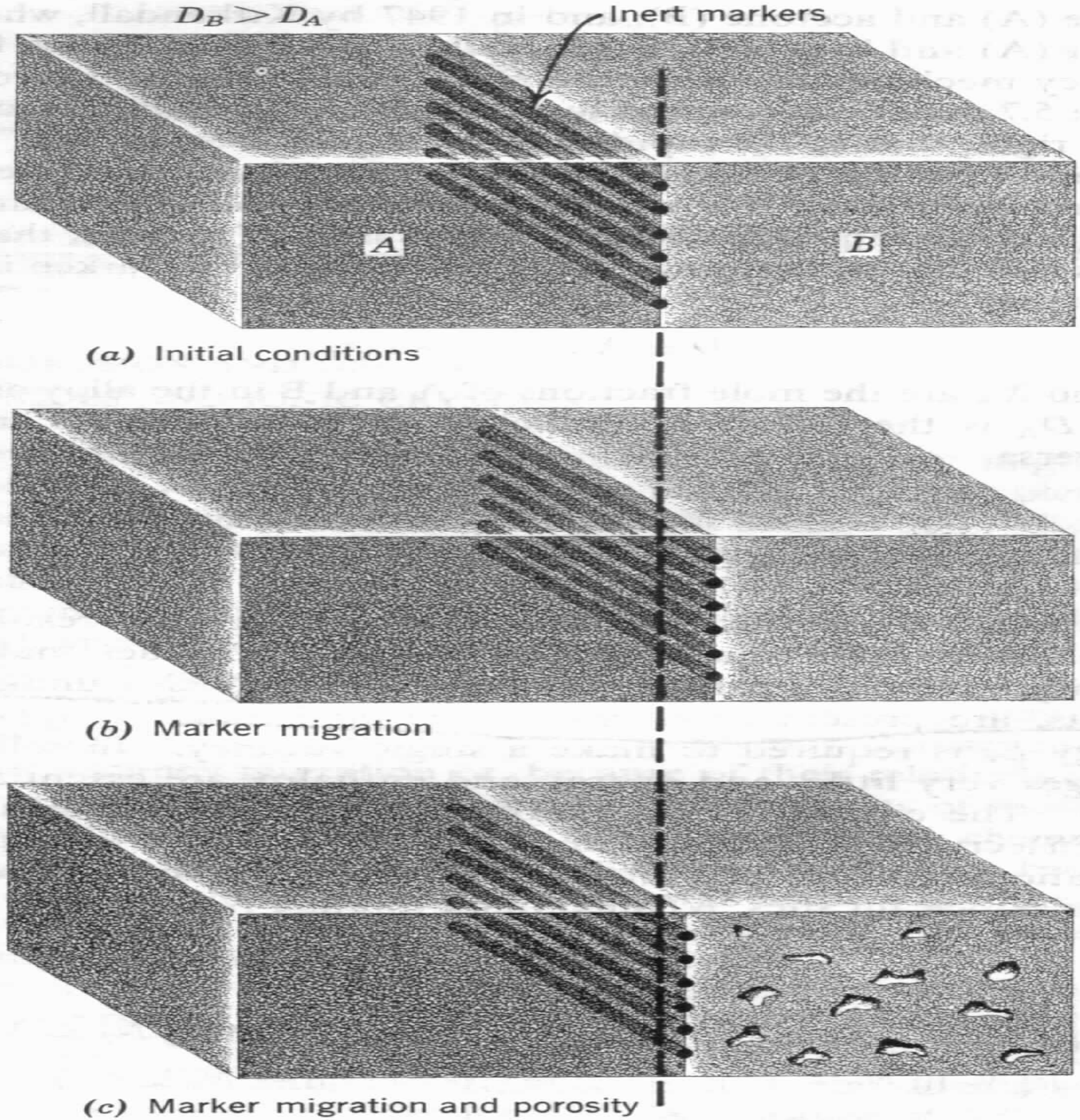

100 percent B
100 percent A
Concentration of component B
Concentration of component A
0 percent B
0 percent A
Original interface (position of weld)


Metal B
Metal A
Wire
Weld


Pure metal B
Pure metal A
Wire
Interface or weld
x
100 per cent A
Original interface
Wire
Penetration curve
(per cent A)
0 per cent A

(A)

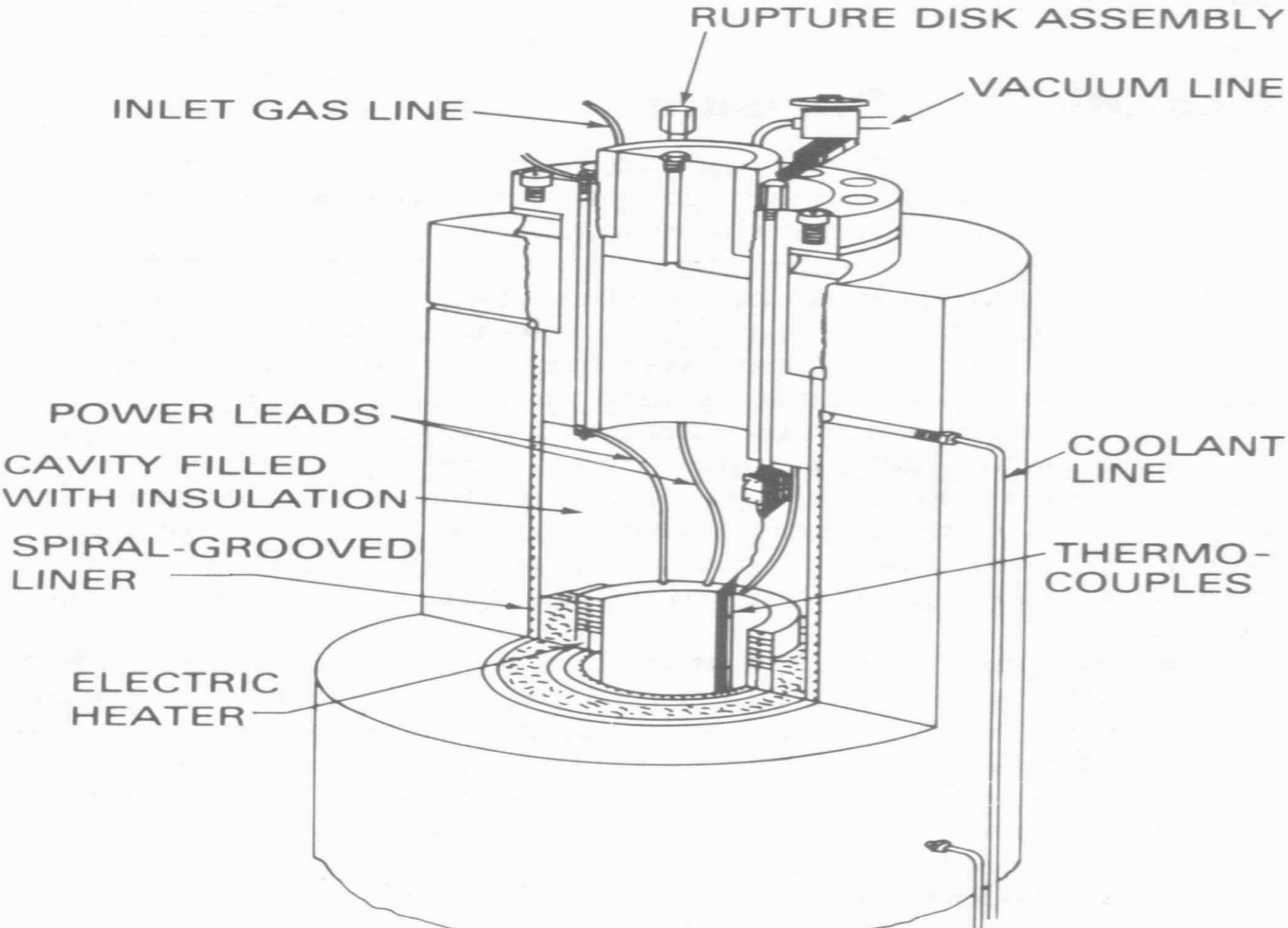
(B)



(a) Initial conditions

(b) Marker migration

(c) Marker migration and porosity



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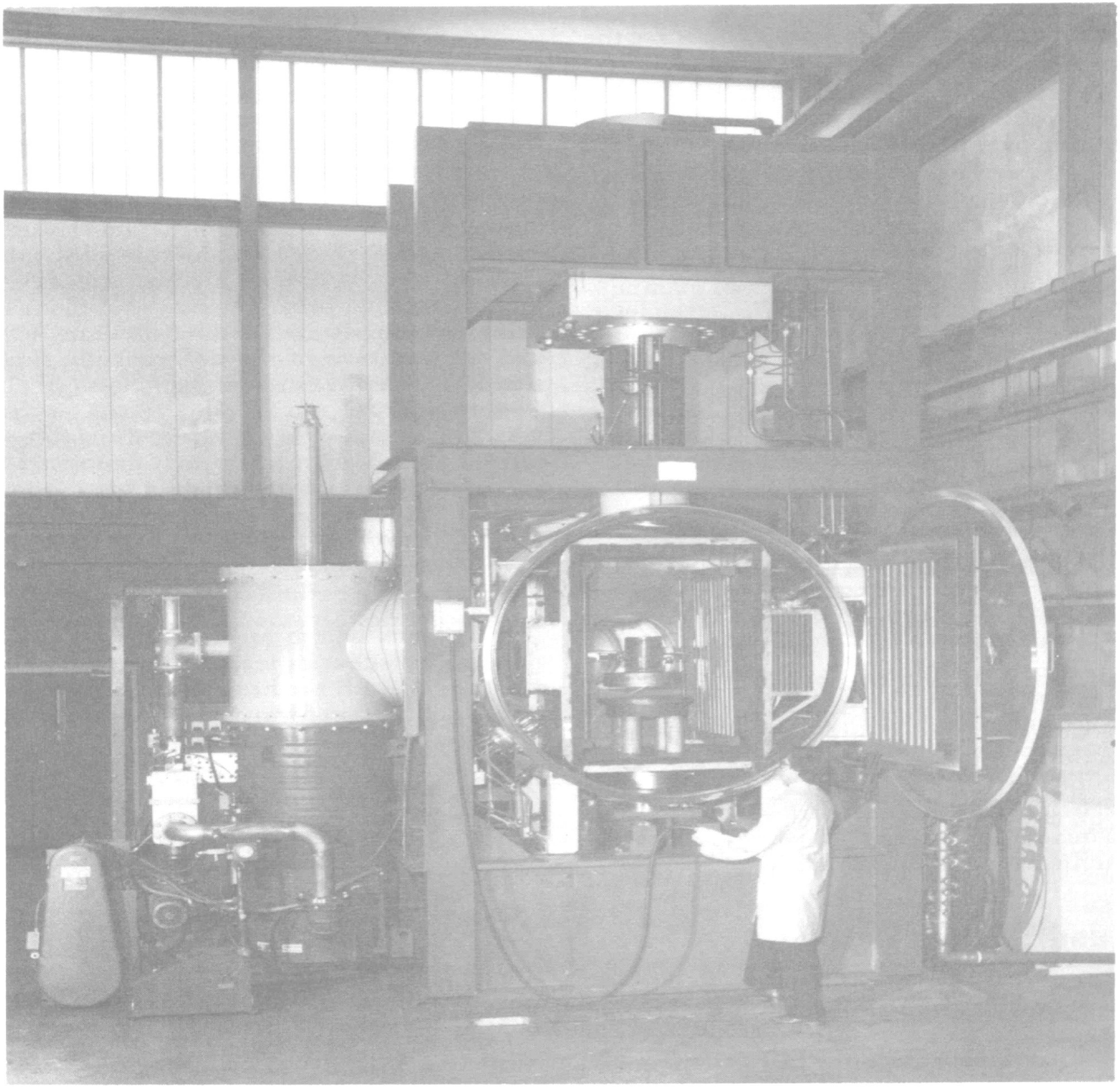


Applications of Diffusion Welding

- Application in titanium welding for aero-space vehicles.
- Diffusion welding of nickel alloys include Inconel 600, wrought Udimet 700, and Rene 41.
- Dissimilar metal diffusion welding applications include Cu to Ti, Cu to Al, and Cu to Cb-1%Zr. Brittle intermetallic compound formation must be controlled in these applications.

Titanium Diffusion Welding

- **Temp As High As Possible Without Damage to Base Metal**
  75 to 100 F below Alpha-Beta Transus (eg 1700F)
- **Time varies with other facts below but 1 hr to 4 hour typical**
- **Pressure near yield (at temp)**
- **Smooth Faying Surface (rough surfaces = more time, pressure)**
- **Clean Surface (usually acid cleaning)**

Space Shuttle designed to have 28 Diffusion Welding Components

Superplastic Formed & Diffusion Bonded Titanium Heat Exchanger

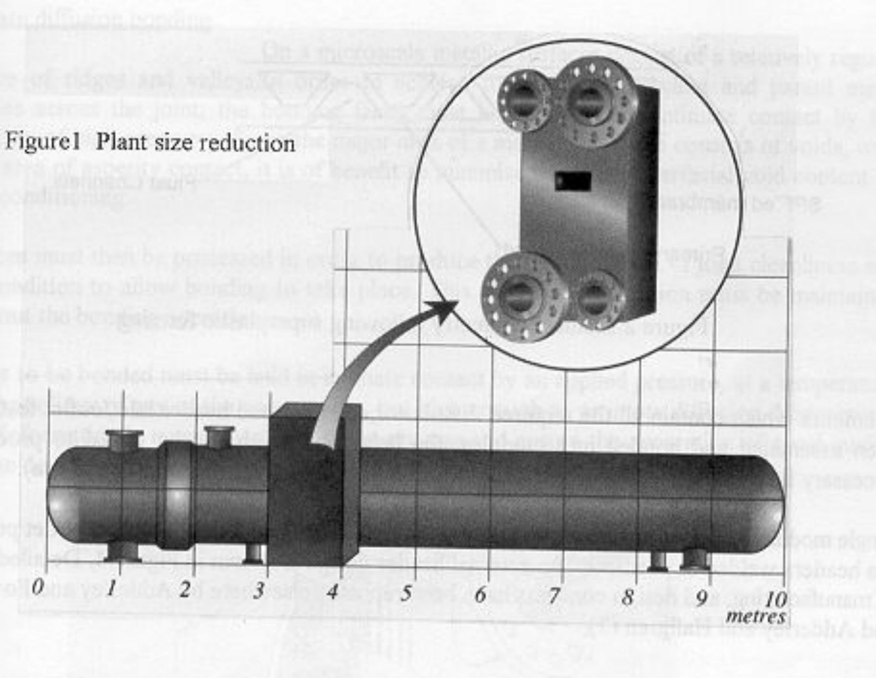
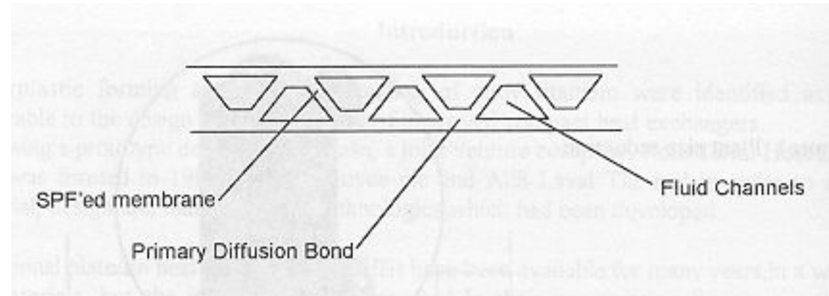
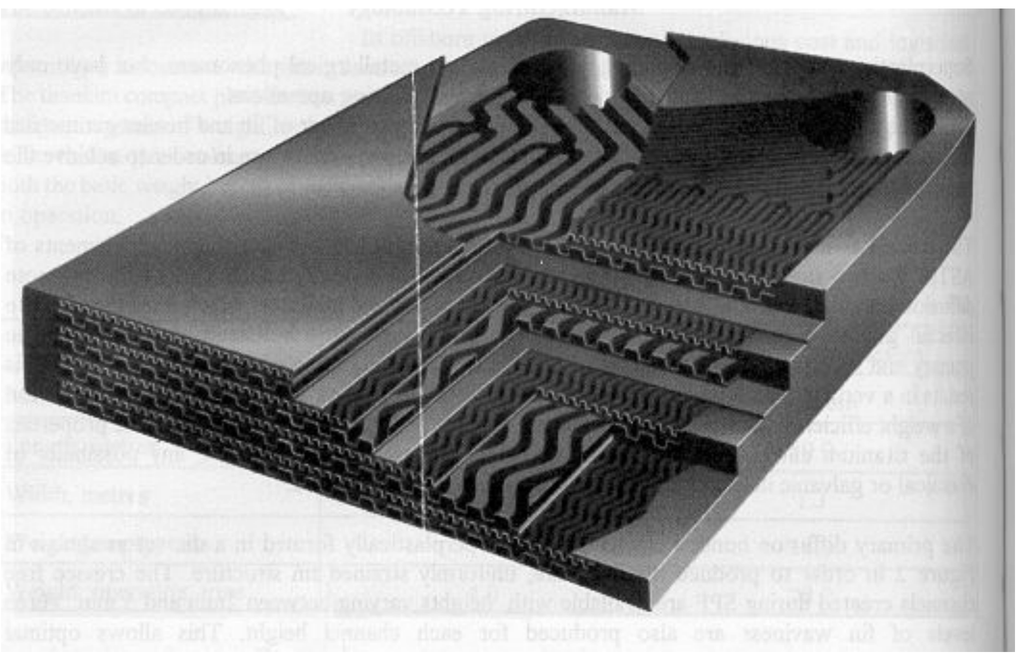
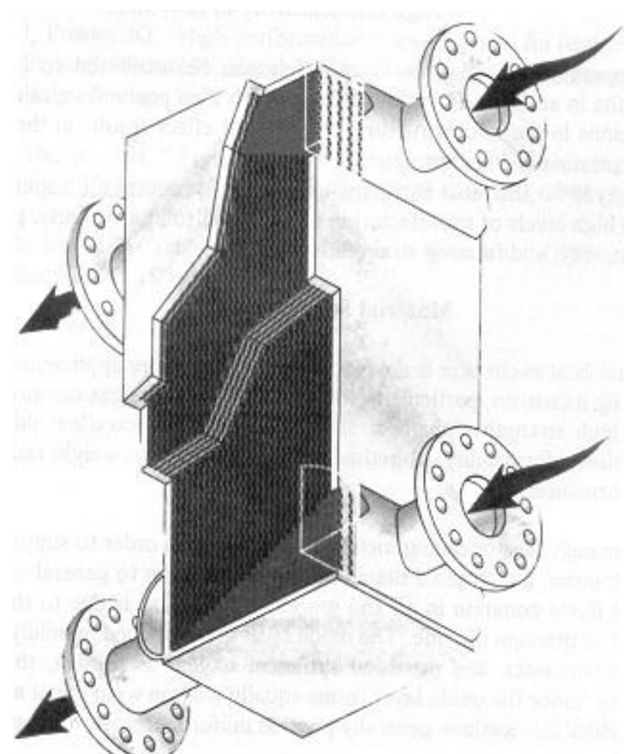


Figure1 Plant size reduction







Froes, FH, et al, “Non-Aerospace Applications of Titanium” Feb 1998, TMS

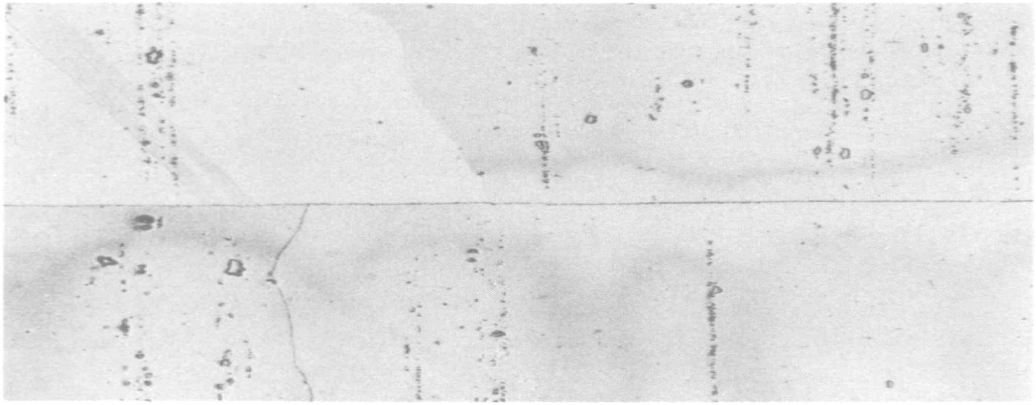
Nickel Diffusion Welding

(More Difficult to Weld)

- Temp close to MP
- High Pressure (because High hot strength)
- Clean Surfaces - Ambient Atmosphere Control
  (Surface Oxides Do Not Dissolve)
- Nickel Filler often used (especially for rough surface)

Typical Diffusion Welding Conditions for Some Nickel-Base Alloys

Base Metal*	Filler Metal	Welding Temp.		Pressure,		Time, h
		°F	°C	psi	kPa	
Inconel 600	Ni	2000	1090	100-500	690-3450	0.5
Hastelloy X	Ni	2050	1120	100-500	690-3450	4
Wrought Udimet 700	Ni-35%Co	2140	1170	1000	6900	4
Cast Udimet 700	Ni-35%Co	2175	1190	1200	8275	4
Rene 41	Ni-Be	2150	1180	1550	10690	2
Mar-M 200	Ni-25%Co	2200	1205	1000-2000	6900-13800	2

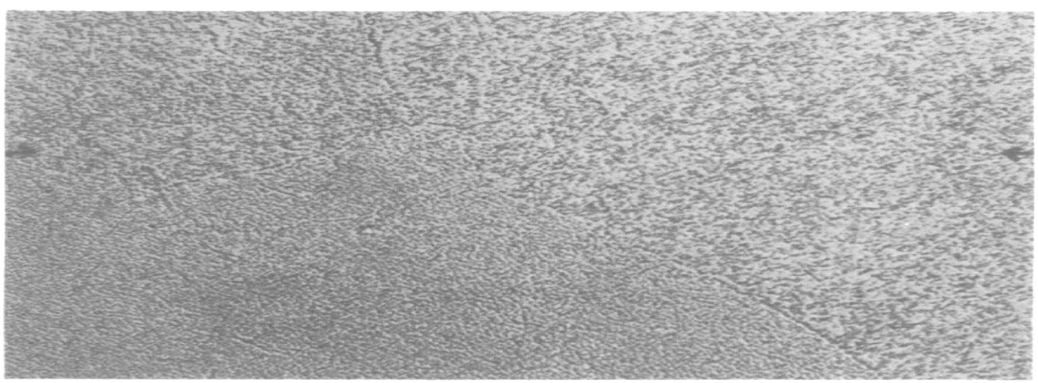


(A)

Without Nickel Filler Metal
Fine Ti(C,N) and $NiTiO_3$
Forms Reducing Strength

(B)

With Ni Filler Metal
No Precipitates Formed
Grain Boundary Migration
But Excessive Ni_3Al ppt.



(C)

With Ni-35% Co
Good Joint Obtained

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Diffusion Welding of Dissimilar Metals

Some Potential Problems

- An intermetallic phase or a brittle intermetallic compound may form at the weld interface. Selection of an appropriate filler metal can usually prevent such problems. Joint designs can help also.

- Low melting phases may form. Sometime this effect is beneficial

- Porosity may form due to unequal rates of metal transfer by diffusion in the region adjacent to the weld (Kirkendall Porosity). Proper welding conditions or the use of and appropriate filler metal or both may prevent this problem.

Table 26.2
Diffusion Welding Conditions for Some Dissimilar Metal Combinations

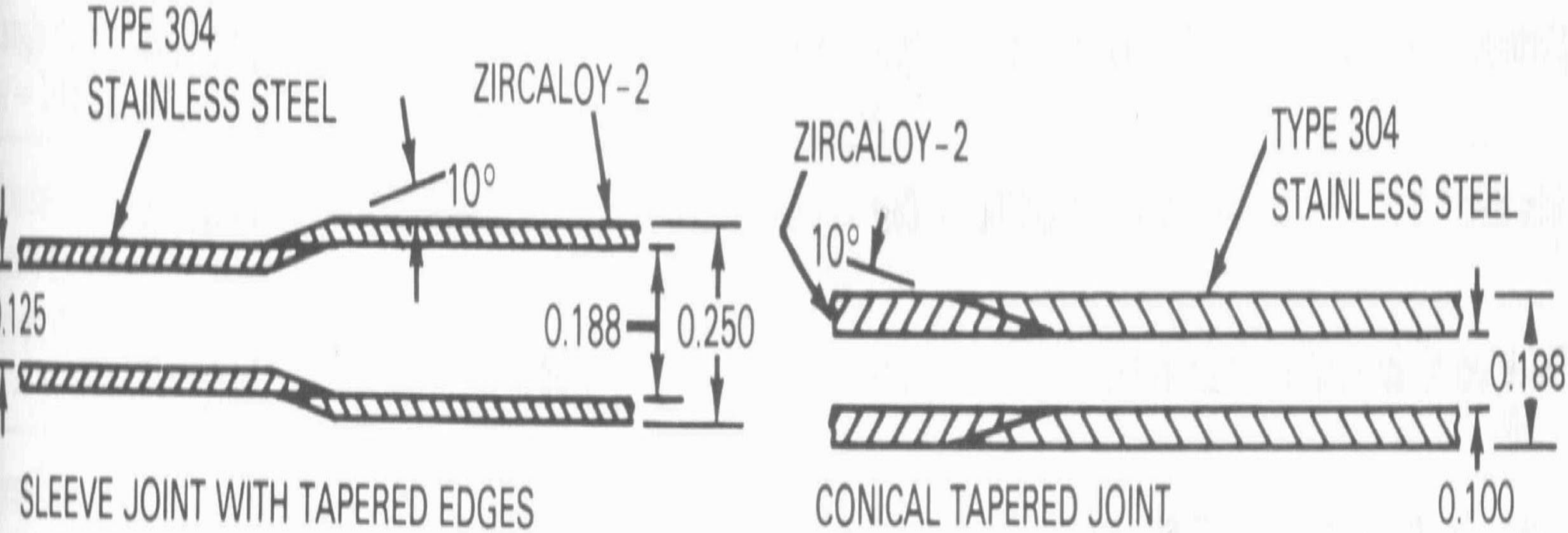
Base Metal Combinations	Filler Metal	Temperature, °F	Temperature, °C	Time,h	Pressure[a], ksi	Pressure[a], MPa	Atmosphere
Cu to Al	—	950	510	0.25	1	7	Vacuum
Cu to 316 Stainless Steel	Cu	1800	982	2	a		Vacuum
Cu to Ti	—	1560	849	0.25	0.7	5	Vacuum
Cu to Cb-1%Zr	Cb-1%Zr	1800	982	4	a		Vacuum
Cu-10%Zn to Ti-6%Al-6%V-2%Sn	—	900	482	8	a		Vacuum
4340 Steel[c] to Inconel 718[b]	—	1730	943	4	29	200	Vacuum
Nickel 200 to Inconel 600[b]	—	1700	927	3	1	7	Not Reported
Pyromet X-15[b] to T-111 Ta alloy	Au-Cu	1100	593	4	30	207	Not Reported
Cb-1%Zr to 316 Stainless Steel	Cb-1%Zr	1800	982	4	a		Vacuum
Zircaloy-2 to 304 Stainless Steel	—	1870-1900	1021-1038	0.5	a		Vacuum

Questions

Some Specific Applications Of Diffusion Welding

Recent Applications of Diffusion Joining in Japanese Industries

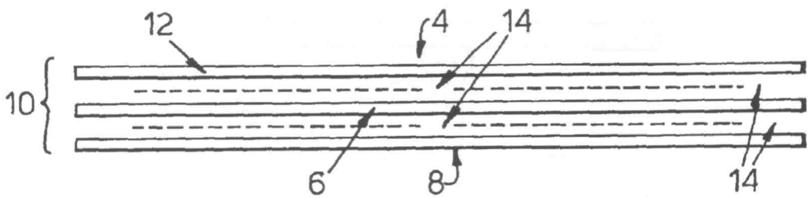
Products	Materials	Reason for Adoption	Previous Method	Product Records
F-15 Fighter Fitting	Ti-6Al-4V	Cost reduction	Machining from forging or plate	more than 1000 parts
Impeller for Liquid Fuel Rocket	Ti-5Al-2.5Sn	Higher quality	—	100 parts
Jewelry	18K gold alloy	Higher quality	Brazing	400 million yen per year
Electrode	Cu-316L stainless steel	New type only possible by DJ	—	2200 parts
Tube sheet	Cupro Ni-mild steel-316L ss	Cost reduction	Rolling or explosive bonding	1000 parts
Chock liner for steel rolling mill	Brass-mild steel	Cost reduction	Solid Cu alloy	100 parts
Cooling plate for cyclotron accelerator	Cu-316Lss	New type only possible by DJ	—	50 parts
Continuous casting mold	wear resistant material - Cu alloy - 304 ss	New type only possible by DJ	—	20 parts



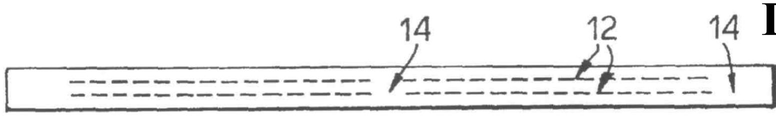
(A) BONDING PRESSURE IS APPLIED BY EXPANSION OF THE STAINLESS STEEL AGAINST THE ZIRCALOY.

(B) BONDING PRESSURE IS APPLIED BY AN AXIAL COMPRESSIVE FORCE FROM AN INTERNAL BAR.

Diffusion Welding and Superplastic Forming for Aircraft Structure

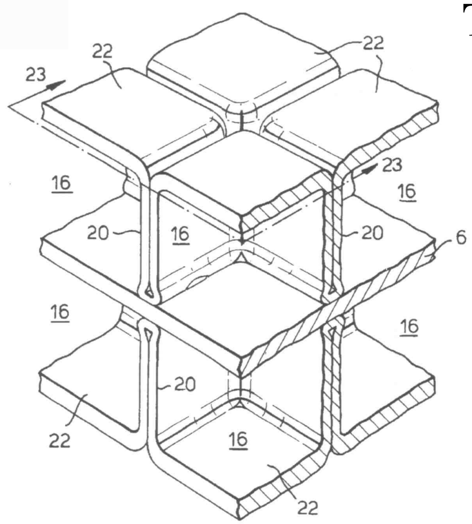


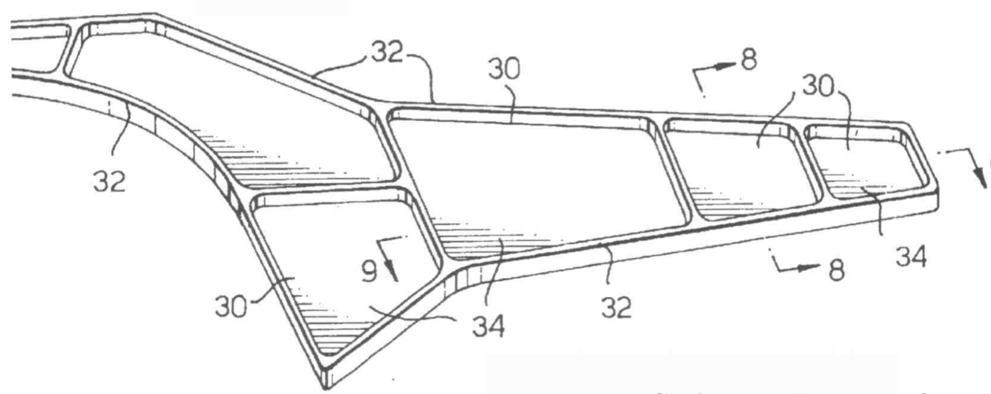
Sheets of superplastic material (ex. Al) stacked with stop-off material (silica) painted on specific areas



Diffusion bonding at 14 (stop-off areas 12)

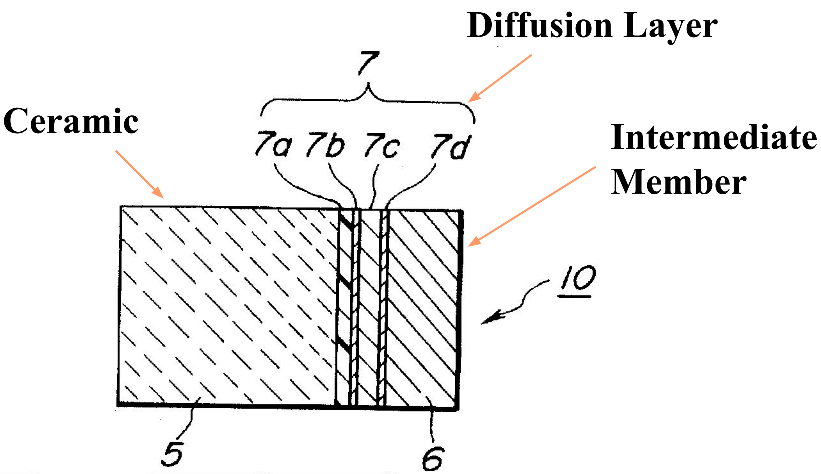
Pressure gas expands stop-off areas
Top cut off if required



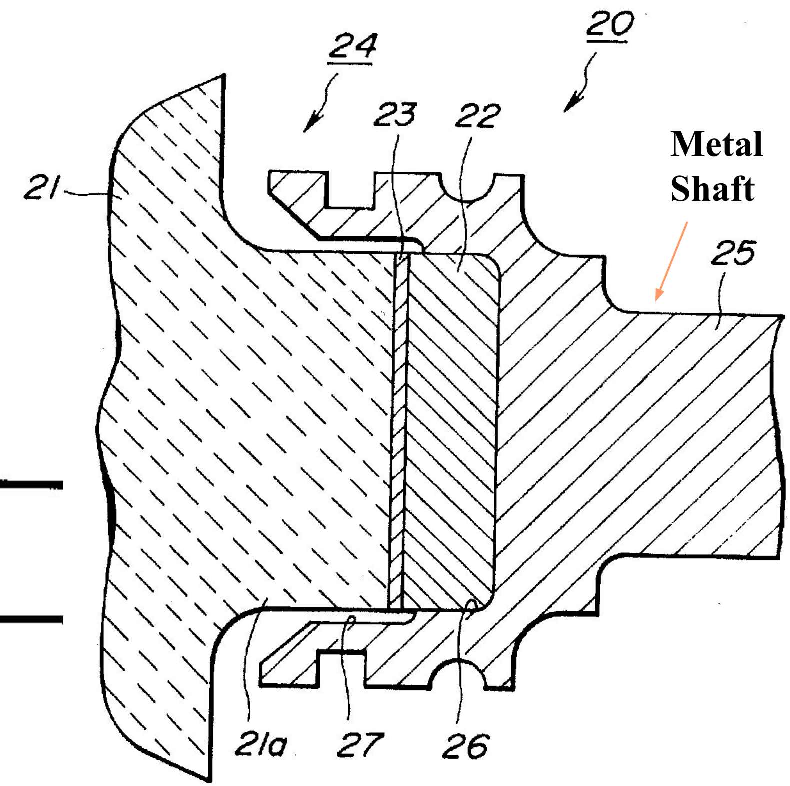


Collier et al, "Method of Manufacturing Structural Parts, Particularly for use in Aircraft" US Patent 6,039,239 Mar 21, 2000

Ceramic Turbocharger Rotor (Diffusion bonded to Intermediate & Friction Welded to Shaft)



No.	Ceramic member	Intermediate member	Metallic member
A	silicon nitride	W alloy	alloy steel
B	silicon nitride	super hard hard alloy	heat resisting steel
C	silicon nitride	silicon nitride-TiN	stainless steel
D	silicon nitride	super hard alloy	Incoloy 903
E	alumina	Incoloy 903	stainless steel
D	alumina	Incoloy 903	stainless steel



Ito, M, et al, "Ceramic-Metal Composite Assembly" Patent 5,881,607 Mar 16, 1999

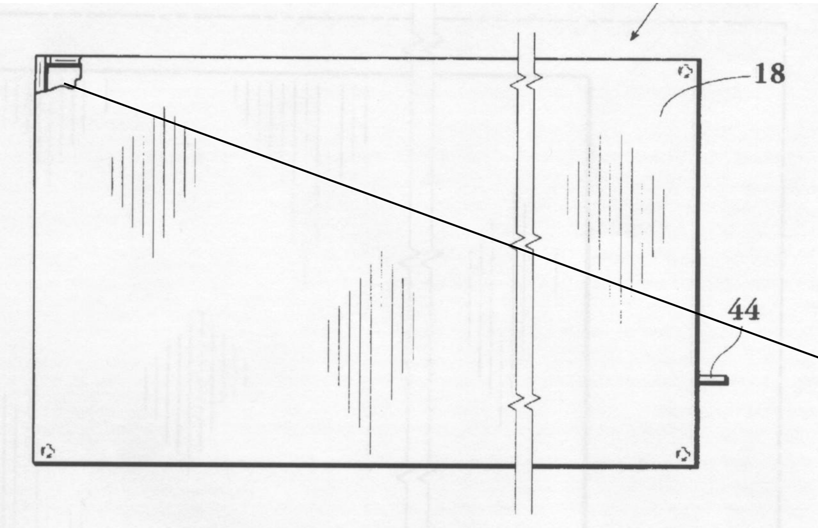
Questions

Diffusion Brazing

- Low Melting inter-layer
- Melts & then diffuses into substrate
- Generally more rapid diffusion

Some Applications

Liquid Phase Diffusion Bonding for Clad Steel Plates



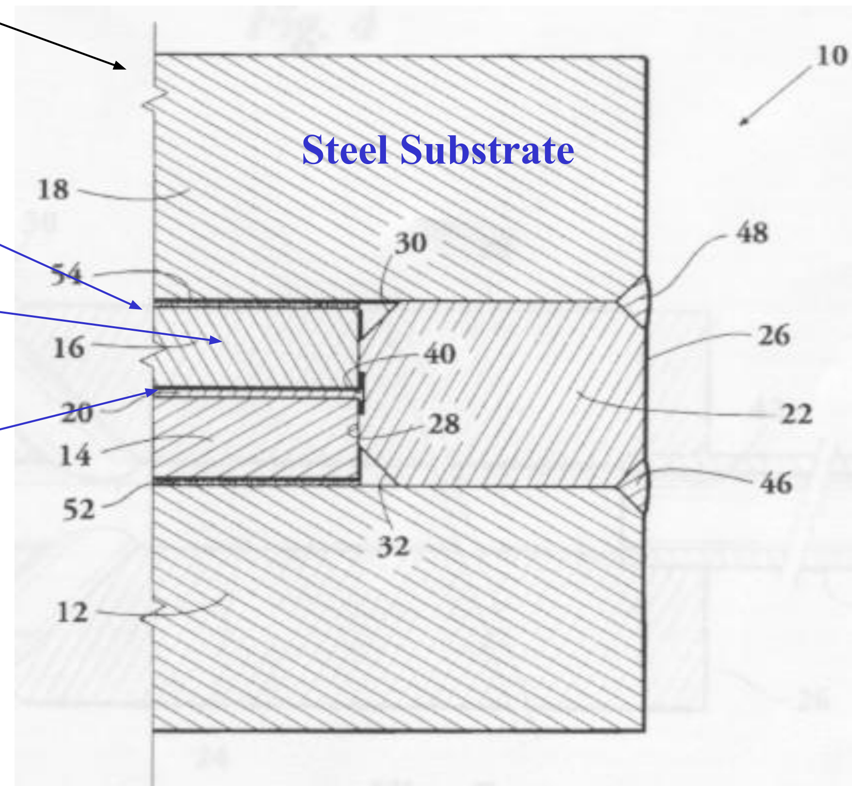
Sheets Stacked (2 sets) with bonding activator between sheets and separator between clad plates

Evacuated & Diffusion Bonded

Bonding Activator (Ni4P)

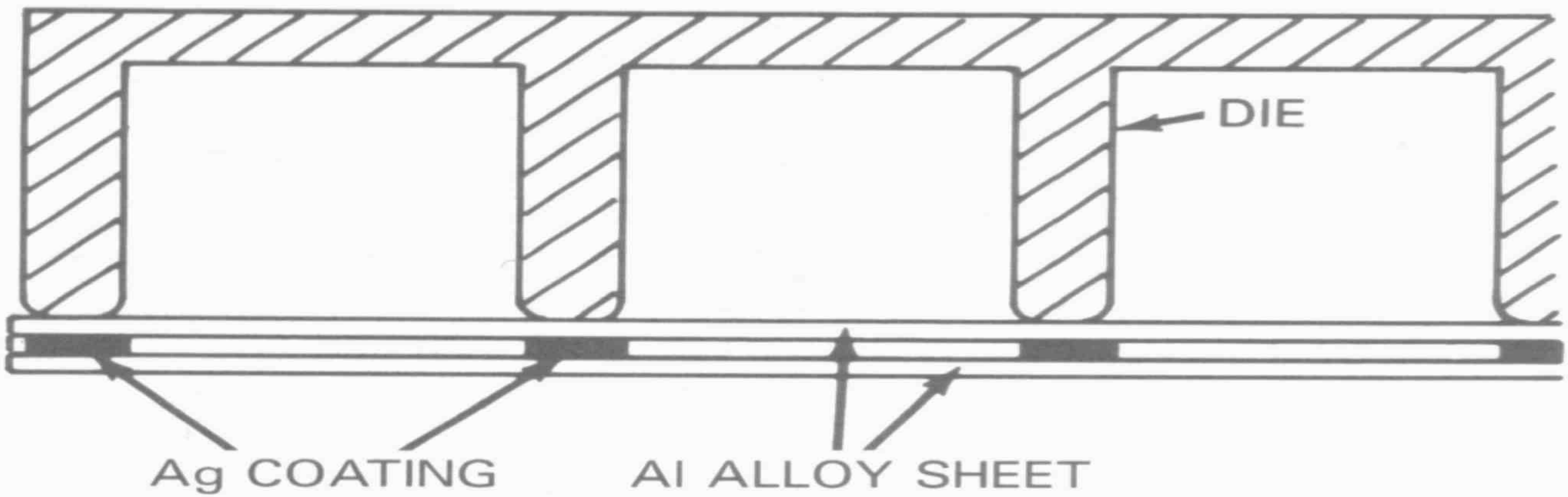
Nickel Clad Material

Separator Compound (silica)

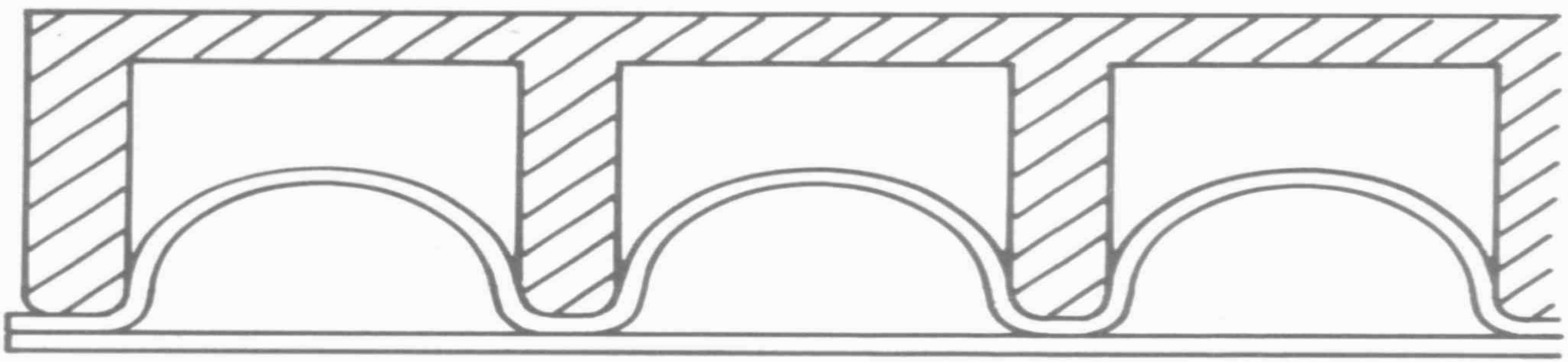


Turner, W. "Method of Manufacturing Clad Metal Plates" US Patent 6,015,080 Jan 18, 2000

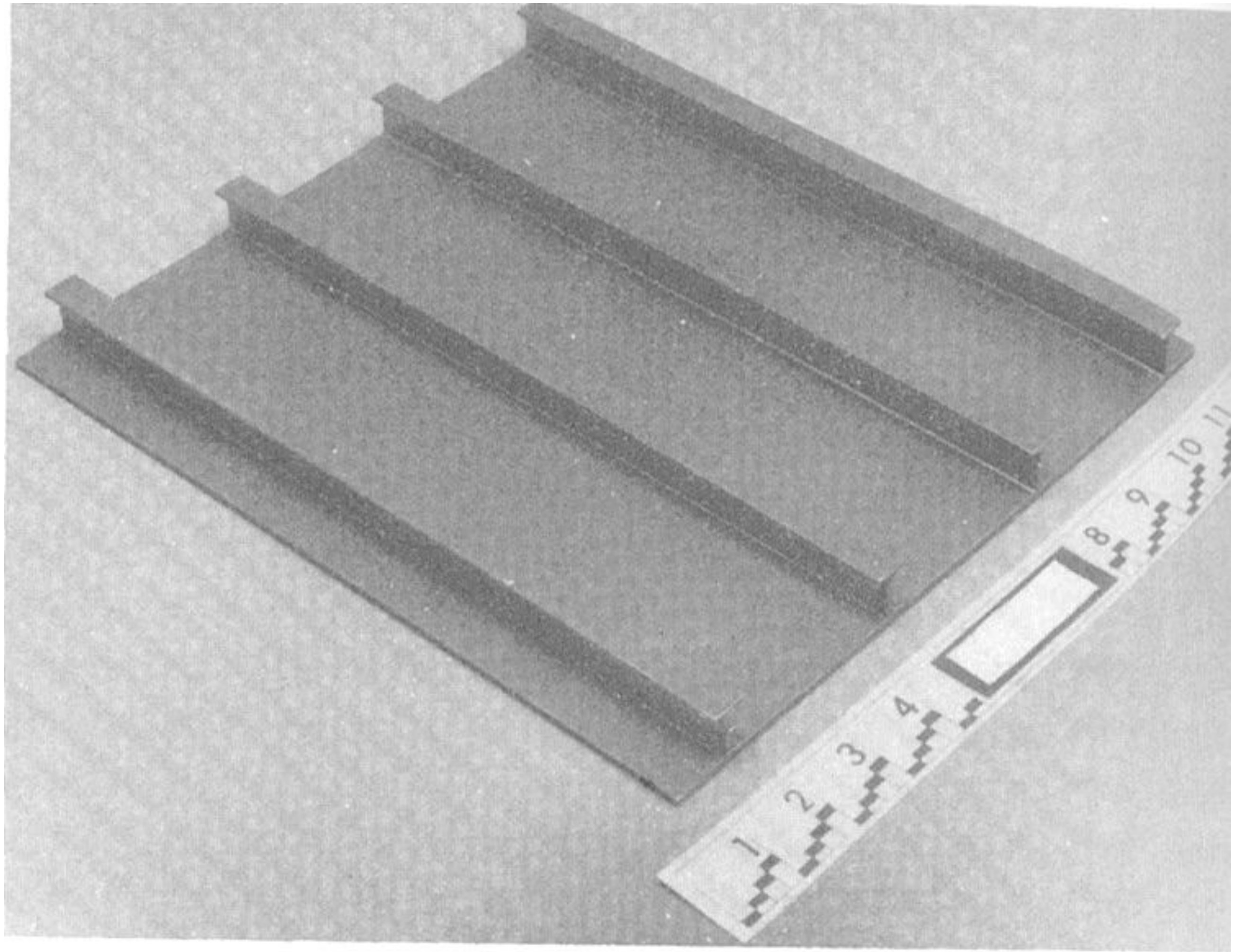
Diffusion Brazing of Aluminum



(A) SETUP PRIOR TO DIFFUSION WELDING

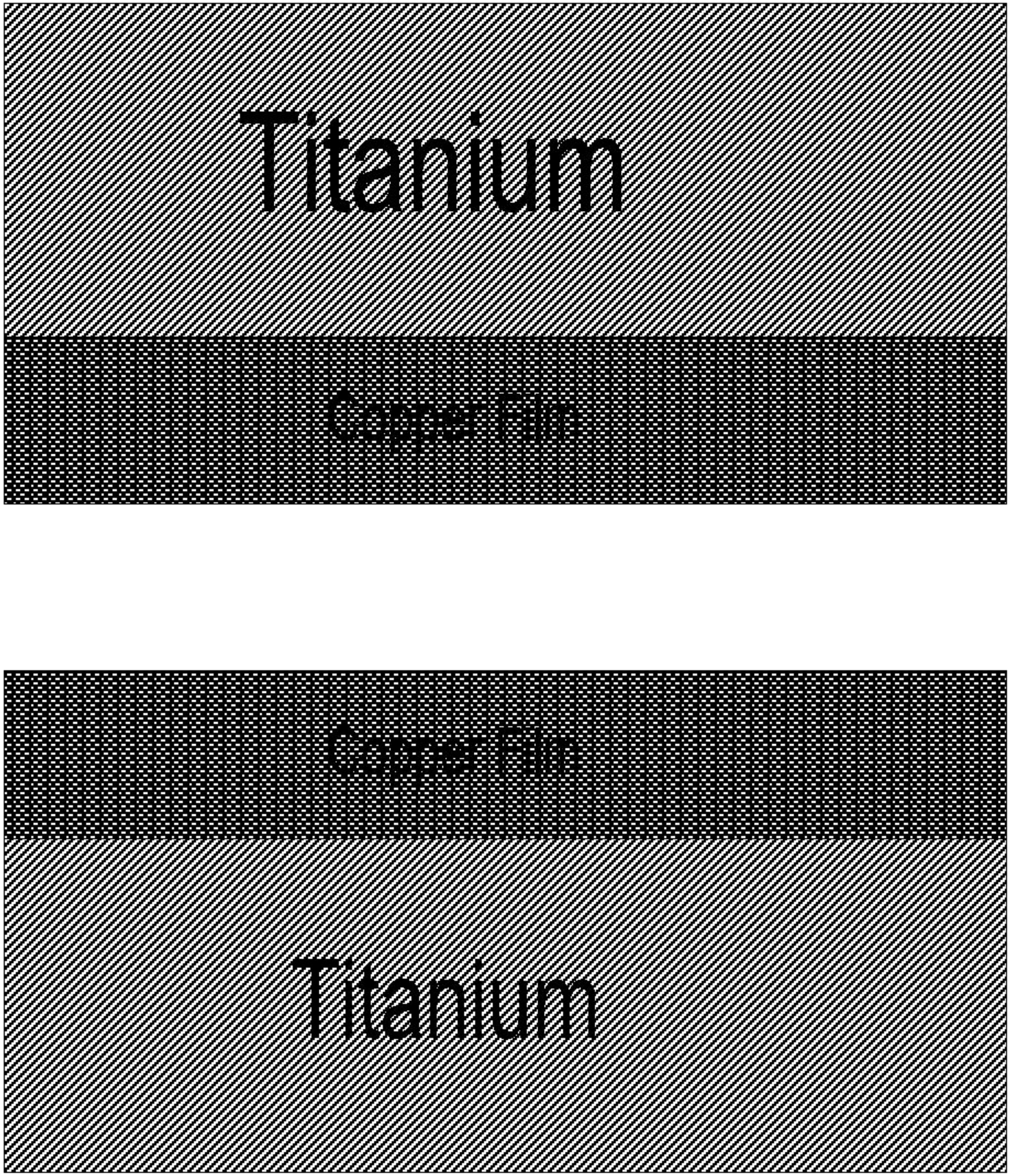


(B) ASSEMBLY AFTER WELDING AND FORMING



A Titanium Alloy Stiffened Sheet Structure Fabricated by Continuous Seam Diffusion Braze

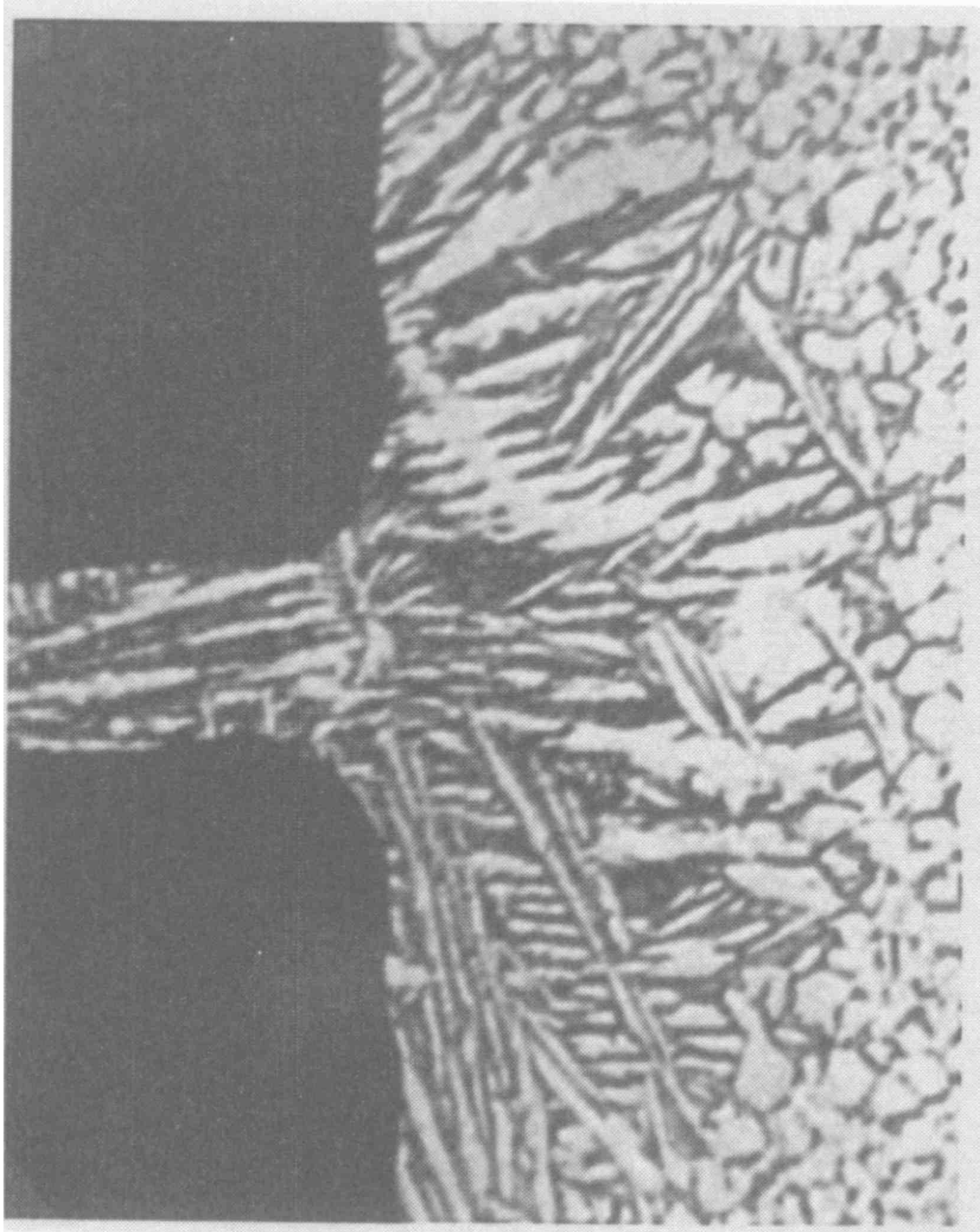
Courtesy AWS handbook



Electrolytically Plated Copper Film

Copper Layers React with Ti to form Eutectic Braze Alloy

Use Similar Parameters as Diffusion Weld



Titanium Braze Plated Copper

A Widmanstaatten structure formed at the braze interface because the plated filler metal stabilized the beta phase.

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Nickel Brazing

Braze Alloy

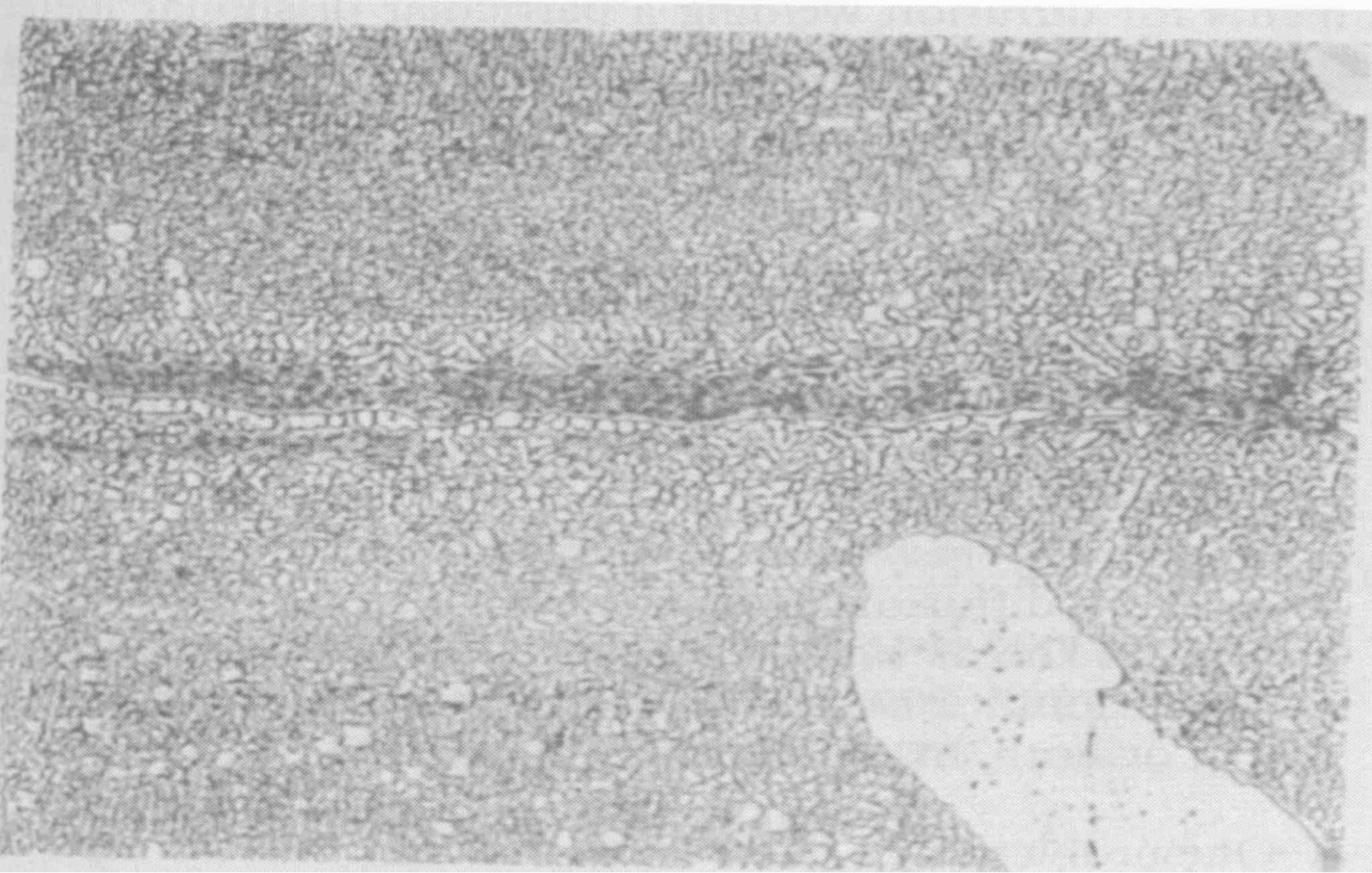
Nickel with melting Point Depressants (Silicon, Boron, Manganese, Aluminum, Titanium or Columbium

Method 1

Melt Braze Metal And Hold At Temp → Temp Depressing Elements Diffuse Into Base Metal → Isothemal Solidification

Method 2

Melt Braze Metal And Hold At Temp → Solidify Braze Alloy → Reheat Below Melting Temp to Diffuse Alloy



Nickel Braze - Isothermal Solidification

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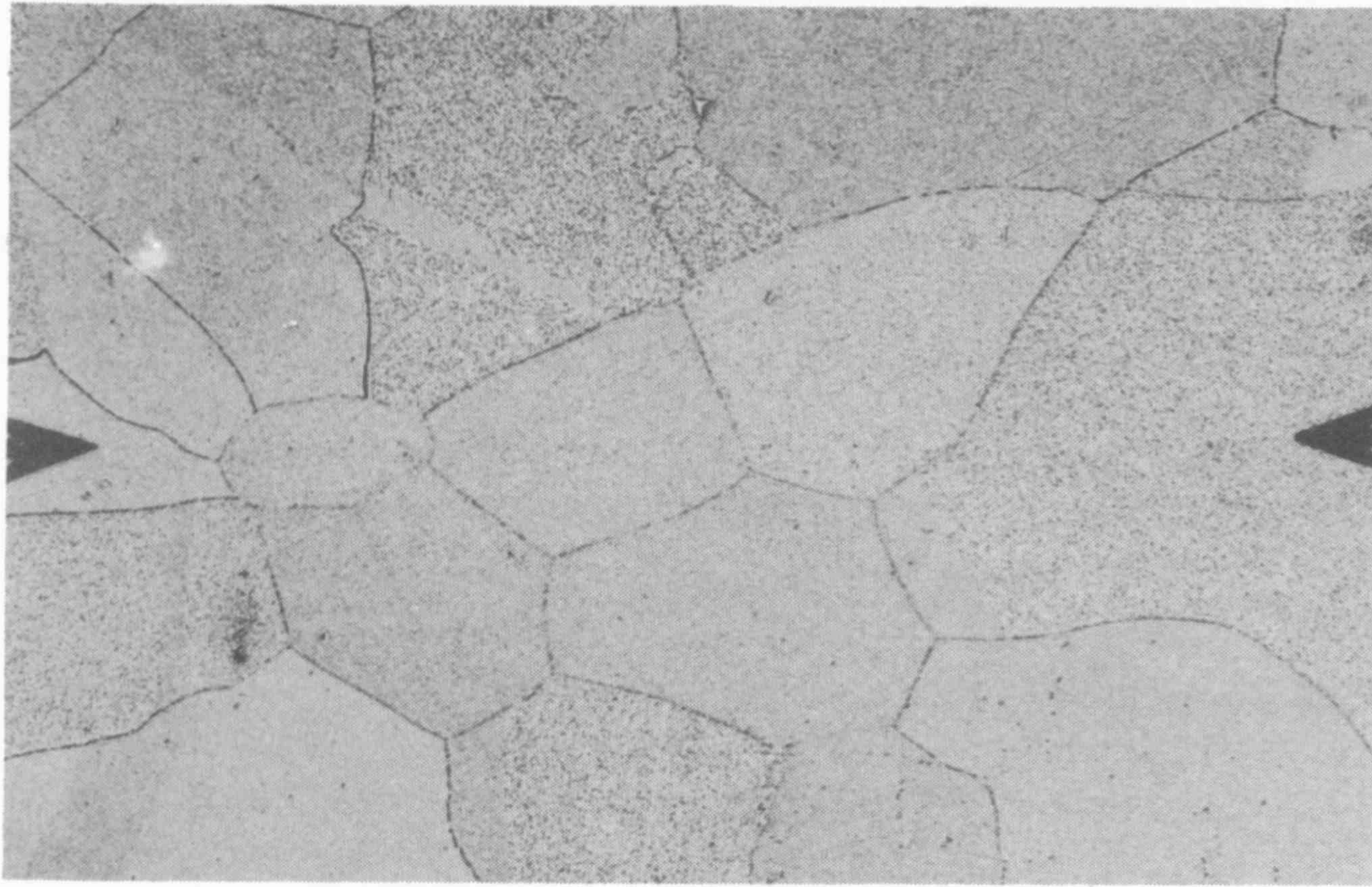

Nickel Braze - Reheat for Diffusion

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