N°1

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Electron Beam Technology

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Electron Beam Welding Basics

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Content

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a. EB Welding (beam material interaction, weldability of materials, …)

b. Design for EB welding (guidelines)

c. Contract Manufacturing Burg (overview, K6000, large parts, deep welds, …)

d. Your Questions

Electron Beam Welding

Beam Material Interaction

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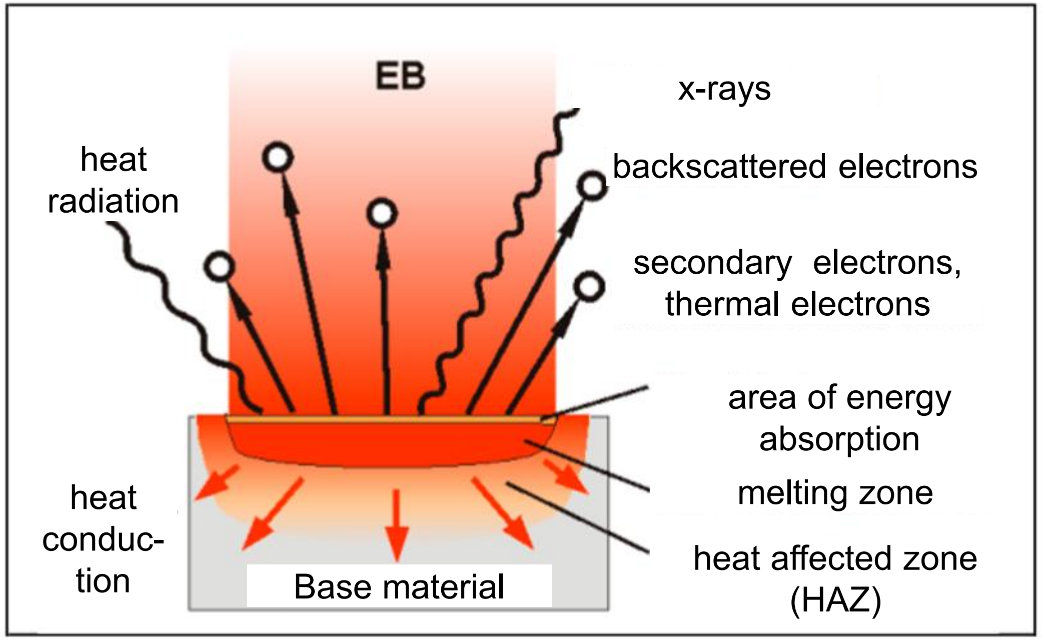
The electron beam causes the following interactions when hitting solid materials:

- Heat
- Backscattered electrons
- X-rays
- Secondary electrons
- Thermal electrons

Mandatory for the process is the heat caused by the kinetic energy of the electrons

Usage especially for part positioning, process surveillance and documentation



Literatur:
V. Adam, U. Clauß, D. Dobeneck, T. Krüssel, T. Löwer; Elektronenstrahlschweißen - Grundlagen einer faszinierenden Technik; pro-beam AG & Co. KGaA; S.8f
R. Zenker, A. Buchwalder; Elektronenstrahlschweißen - Randschichtbehandlung; pro-beam AG & Co. KGaA; S.6

Beam Material Interaction - Electron Beam Welding

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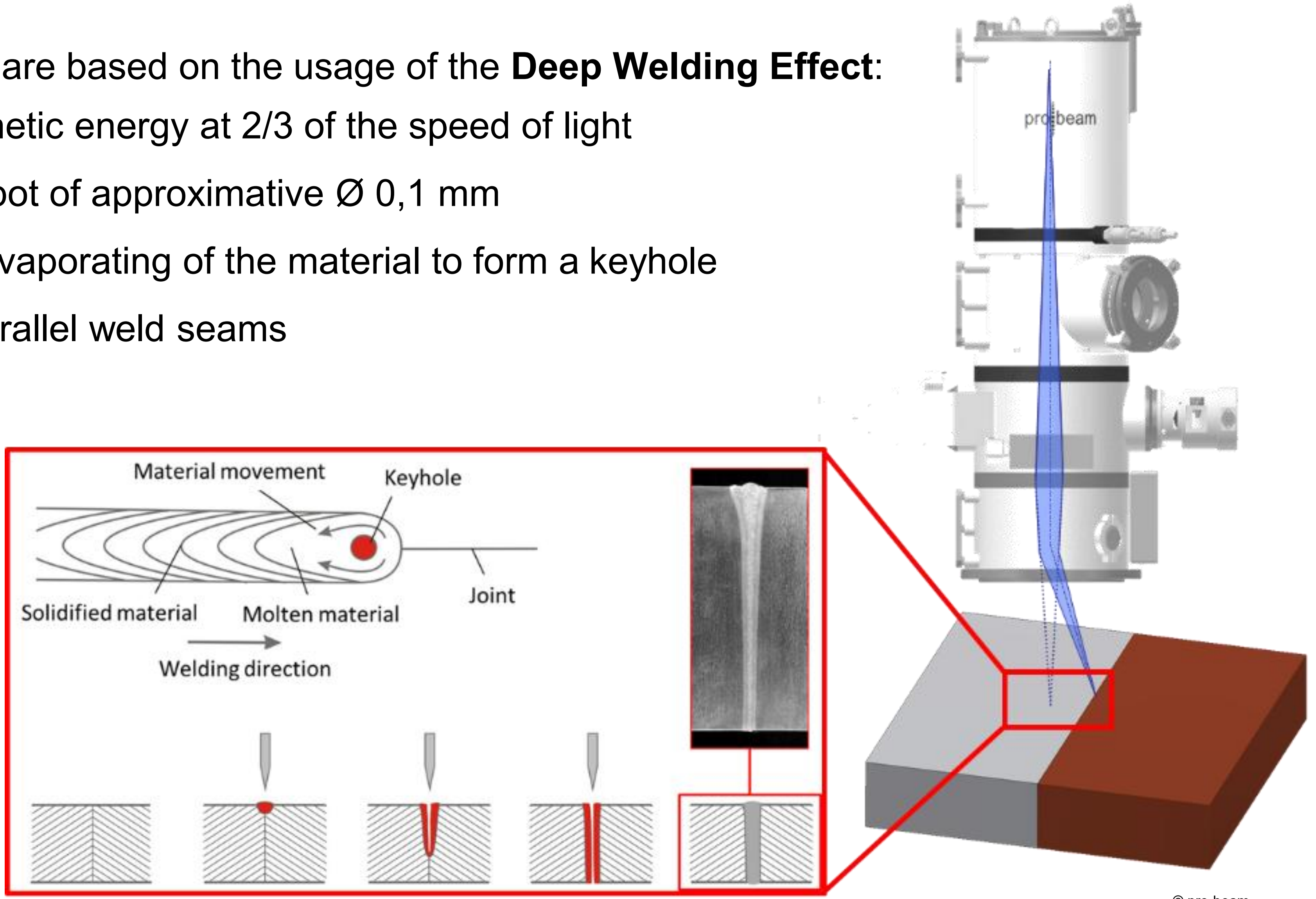
The advantages of EBW are based on the usage of the **Deep Welding Effect**:

- Electrons with high kinetic energy at 2/3 of the speed of light
- Focused on a small spot of approximative Ø 0,1 mm
- Melting and partially evaporating of the material to form a keyhole
- Narrow and almost parallel weld seams



Electron Beam Welding Technology

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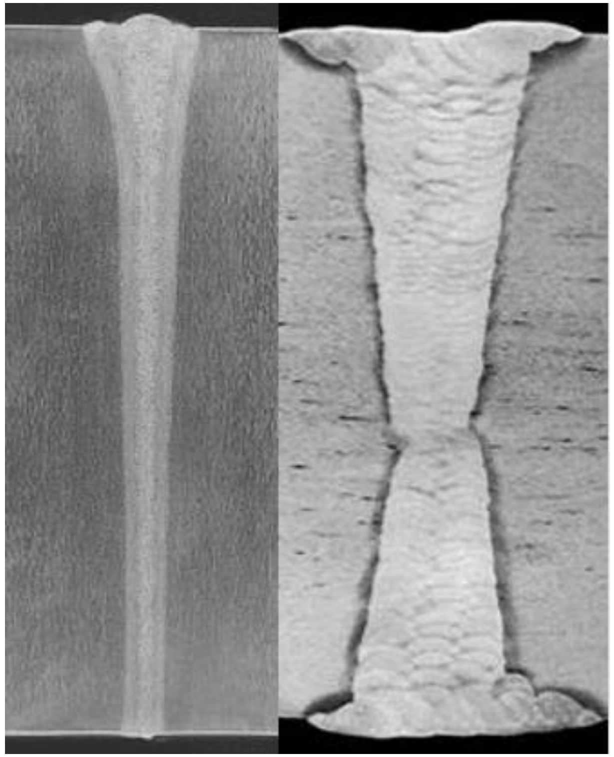
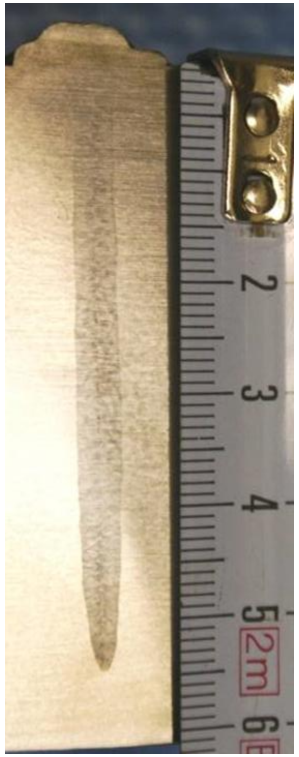
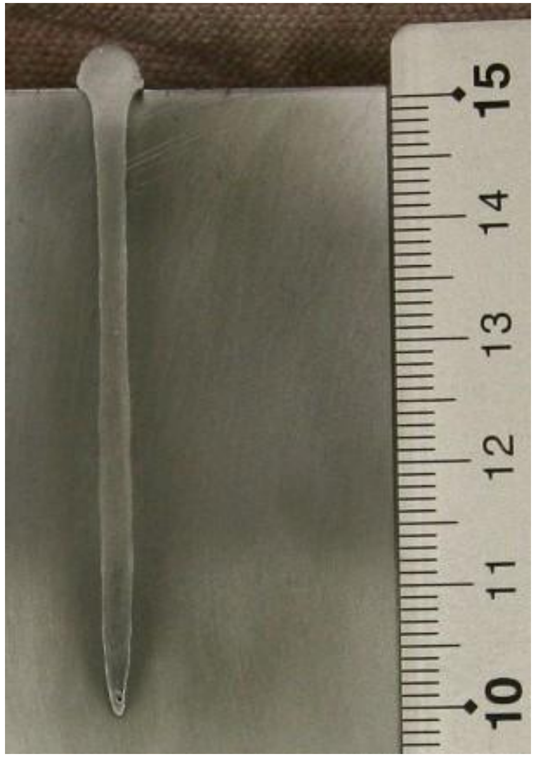
- The deep welding effect allows extremely high welding depths compared to other welding technologies for all metallic materials (also copper)
- Economic advantages are generated by a combination of higher welding depth, higher welding speeds, less distortion and less processing effort


EB vs ARC (1:150 layers)

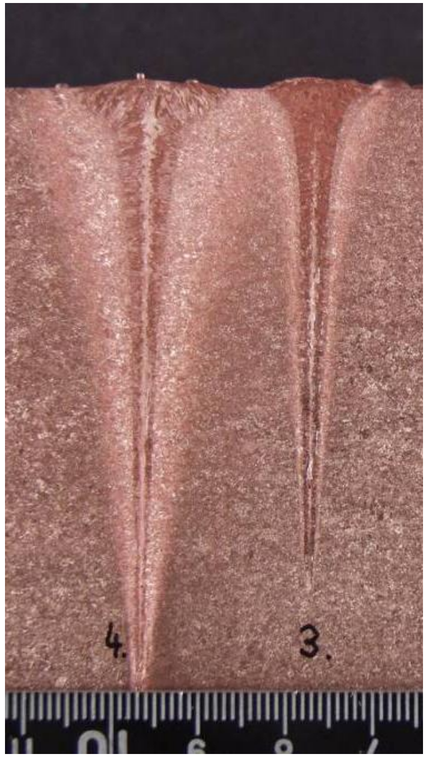
Mild steel



Stainless st.



Aluminum



Copper

Welding depth (one-pass)

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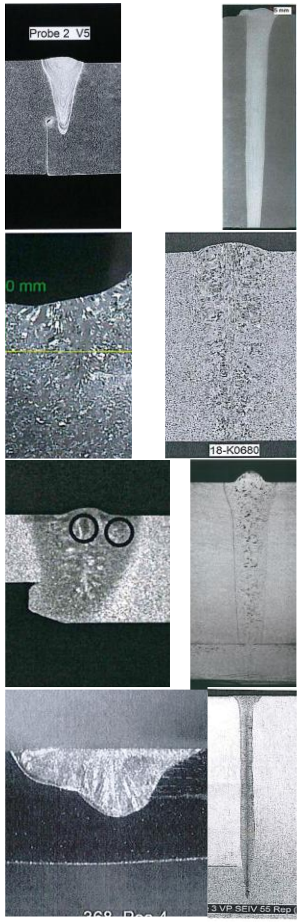
Production Trial stage

1 … Weld seam depth [mm] … 100 150 200



Alumi-
num

120

200

Cooper

60

80

Titan

60

100

Steel,
Stainl.,
Nickel-
based

100

150

150 … Welding velocity [mm/s] … 1

0,1 … Beam power [kW] … 45

Material processing Electron Beam

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Suitable materials for electron beam welding:

Materials - iron-based:
- Non- and low-alloyed steels
- Mild steel
- Heat-resisting steel
- Quenched and tempered steel
- Case-hardening steel
- High-alloyed steel
- Stainless steel
- Duplex stainless steel
- High speed steel
- Cast iron
- …

Materials - non-ferrous:
- Nickel / nickel-based alloys
- Aluminum
- Magnesium
- Copper / Alloys of copper
- Titanium
- Molybdenum
- Niobium
- Tantalum
- Tungsten
- Zirconium
- …

Material processing Electron Beam

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Ferritic / martensitic steels (including stainless steels) & iron

- Penetration depth of 0,1 mm up to 100 mm in one layer possible
- Based on the high cooling rate (typical for EB-welding) the toughness in the heat affected zone can be decreased
- Preheating / post heat treatment (e.g. by electron beam) can be necessary for steels with > 0,2% C
- Steel must be degaussed before EB-welding (approx. <2 Gauss)

Stainless steels (austenitic / austenitic - ferritic)

- Penetration depth of 0,1 mm up to 100 mm in one layer possible
- No issue with tempering colors because of the vacuum
- Be aware of discoloration due to metal-vapor
- Weld seams of austenitic steel have ultra high strength close to base material, especially in hot and cold environments like for cryogenic applications at 20K or lower

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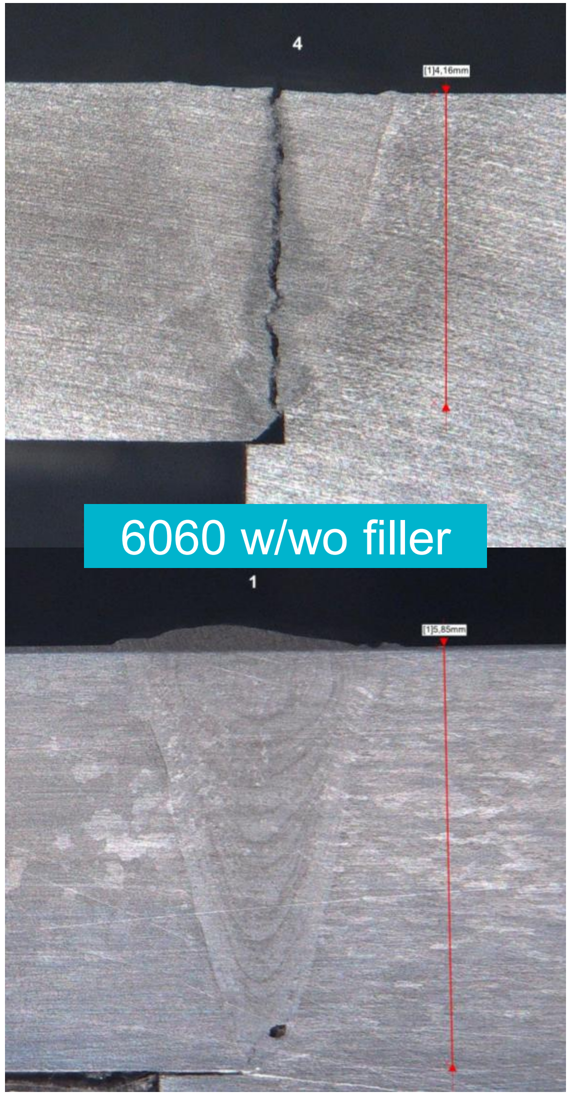
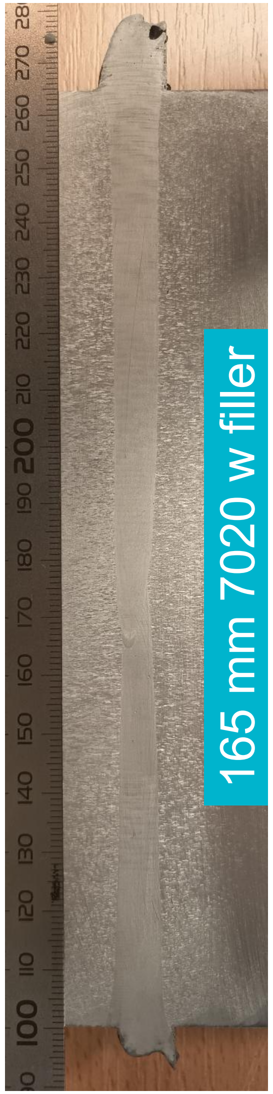
Aluminum

- Penetration depth up to 120 mm in one layer without preheating possible
- Non-heat-treatable alloys like 1000 / 3000 / 5000 series are considered favorable for EB welding
- Heat-treatable alloys like 2000 / 6000 / 7000 series have limited weldability and can only be welded under specific conditions
- The weldability of 6XXX alloys is limited because they are prone to hot cracking, they should be welded with 4XXX filler material only
- The weldability of 7XXX alloys is limited due to their high tendency for hot cracking and the adverse effects of high zinc content, they should be welded with 5XXX filler material only





Copper / Alloys of copper

- Penetration depth of 1 mm up to 60 mm in one layer possible
- Preheating of copper for EB-welding not necessary
- Oxygen-free copper is favorized
- Alloys with zinc ("brass") are not weldable by EB-welding
- Alloys with tin, nickel, aluminum have good weldability
- Alloys with chromium and/or zirconium form hard, brittle intermetallic compounds, which remain insoluble in the base material > this can lead to crack initiation and reduced joint integrity

Nickel-based alloys

- Penetration depth of 0,1 mm up to 100 mm in one layer possible
- Be aware of 2 cracking phenomena: solidification* and liquation** hot cracking
- To avoid hot cracks the energy input should be minimized and the design should allow a free weldment shrinkage

- * Solidification hot cracking occurs during the final stages of weld pool solidification, when tensile stresses act on a weak interdendritic structure and low-melting constituents segregate at grain boundaries.
- ** Liquation hot cracking arises when low-melting phases in the heat-affected zone partially melt and resolidify under tensile stress, leading to crack formation along grain boundaries.

Material processing Electron Beam

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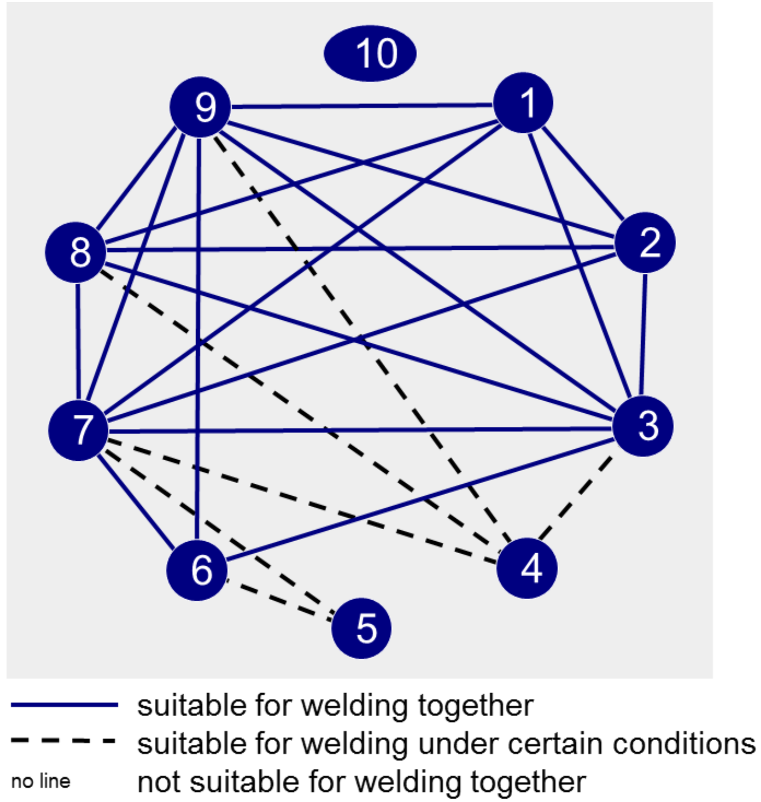
Suitable material combinations for electron beam welding:



Source: DVS Reference EB-Welding

- 1 Unalloyed and low alloyed low carbon steels, in particular structural steels, not free machining steels.
- 2 High alloy steels with high carbon contents.
- 3 High alloy very low carbon steels, in particular corrosion resistant steels.
- 4 Cast irons with lamellar or spheroidal graphite, black tempered cast iron.
- 5 Aluminum alloys except for those containing zinc.
- 6 Pure copper, low alloy copper.
- 7 Copper alloys except for those containing large amounts of zinc.
- 8 Nickel and nickel-based alloys.
- 9 Cobalt alloys except for hard materials containing large amounts of carbides.
- 10 Titanium and titanium alloys.

Design for EB Welding

Design for Electron Beam Welding

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Mandatory rules are easy to find in **DVS guidelines 3201** und standard **DIN EN 1011-7.**

Quelle:
DVS-Merkblatt 3201 2019-04

April 2019

DVS VERBAND
DVS – Deutscher Verband
für Schweißen und
verwandte Verfahren e. V.

Merkblatt
DVS 3201

Ersetzt Ausgabe Mai 2001

Merkblatt DVS 3201

Grundsätze für das Konstruieren von Bauteilen für das Strahlschweißen im Grob-, Fein- und Hochvakuum

Ausschuss für Technik im DVS

Arbeitsgruppe V 9 "Strahlschweißen"

Untergruppe V 9.1 "Elektronenstrahlschweißen"

Schweißtechnik — Richtlinien **3.7**

Oktober 2004

DIN EN 1011-7 — DIN

ICS 25.160.10

Schweißen –
Empfehlungen zum Schweißen metallischer Werkstoffe –
Teil 7: Elektronenstrahlschweißen;
Deutsche Fassung EN 1011-7:2004

Welding –
Recommendation
Part 7: Electron b
German version E

Soudage –
Recommandation

3.7 Richtlinien

EN 1011-7:2004 (D)

C.2 Gruppeneinteilung für Aluminium und Aluminiumlegierungen

Aluminium und Aluminiumlegierungen sind wie in Tabelle C.2 aufgeführt eingestuft. Die angegebenen Daten beruhen auf die für die Bezeichnung der Legierungen verwendeten Elementgehalte.

Tabelle C.2 — Gruppeneinteilung für Aluminium und Aluminiumlegierungen

Gruppe	Untergruppe	Aluminium und Aluminiumlegierungssorte	Schweißeignungsklasse
21		Reinaluminium mit ≤ 1 % Verunreinigungen oder Legierungsbestandteilen	I
22		Nicht warmaushärtbare Legierungen	
	22.1	Aluminium-Mangan-Legierungen	I
	22.2	Aluminium-Magnesium-Legierungen mit Mg ≤ 1,5 %	I
	22.3	Aluminium-Magnesium-Legierungen mit 1,5 % < Mg ≤ 3,5 %	II
	22.4	Aluminium-Magnesium-Legierungen mit Mg > 3,5 %	I
		Warmaushärtbare Aluminiumlegierungen	

Quelle:
DIN EN 1011-7 2004-10

Design for Electron Beam Welding

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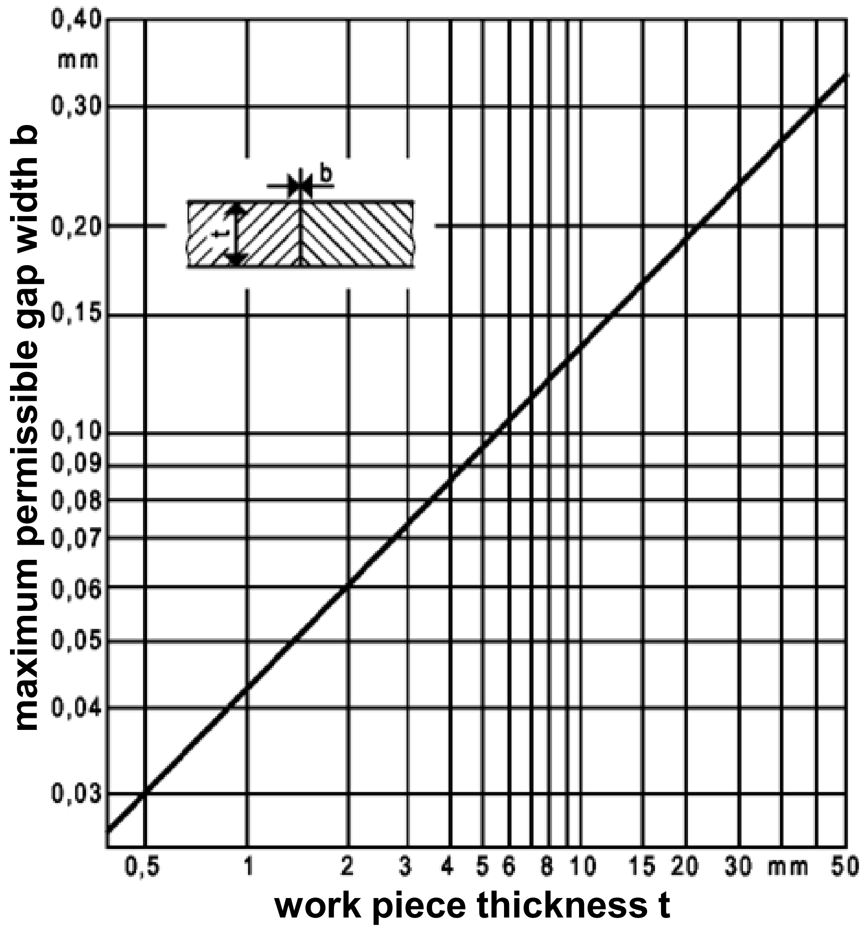
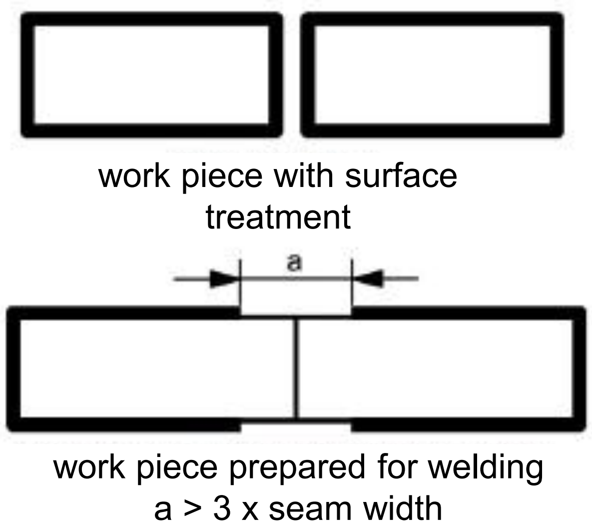
- „gap-less“ for welding without filler material
- „clean“ especially in the melting zone

Quelle:
NA 092 Normenausschuss Schweißtechnik (NAS)
NA 092-00-15 AA Arbeitsausschuss Elektronenstrahlschweißen (DVS AG V 9.1)
E-Mail des Bearbeiters im DIN: holger.zernitz@din.de
DVS-Merkblatt 3201 2001-10



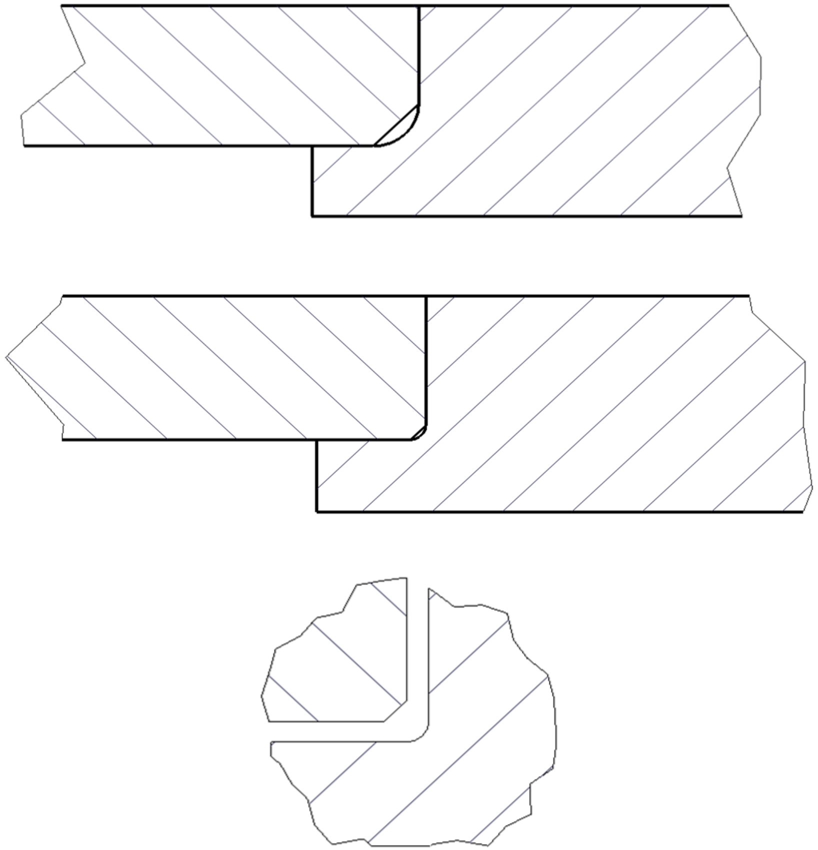


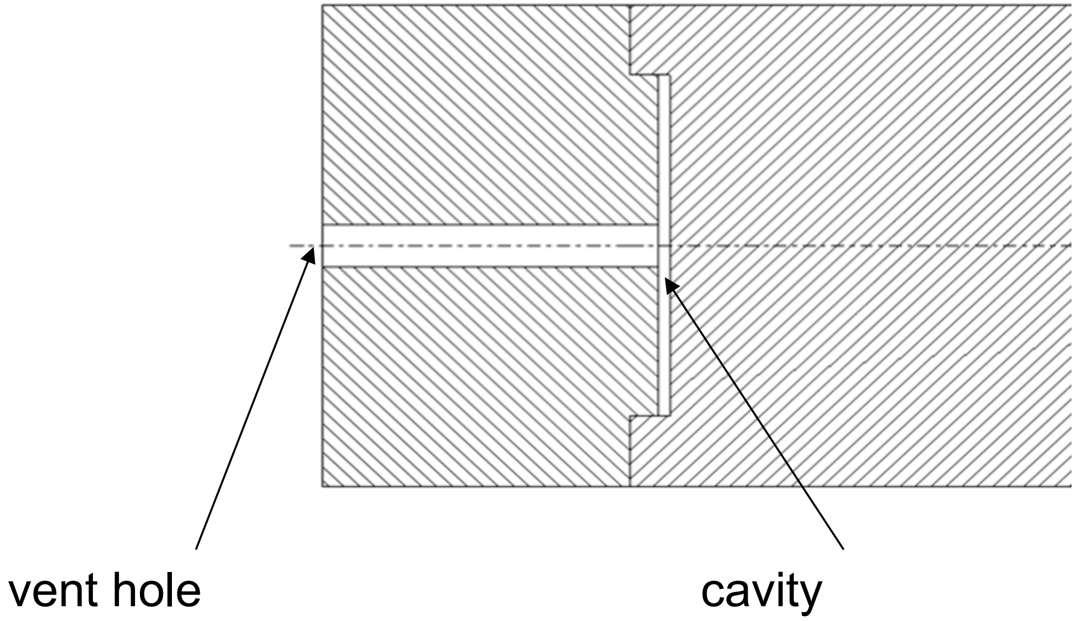
Prerequisites:
- Metallic blank
- Free of layers (rolling surface, hardening, nitried cases…)
- Free of grease, fat, oil, cooling fluids

Quelle:
DVS-Merkblatt 3201 2019-04

Design for Electron Beam Welding

- „no cavities“ - cavities must be vented or minimised
- typical combinations of fase and radius are 0,5x45° & R0,3





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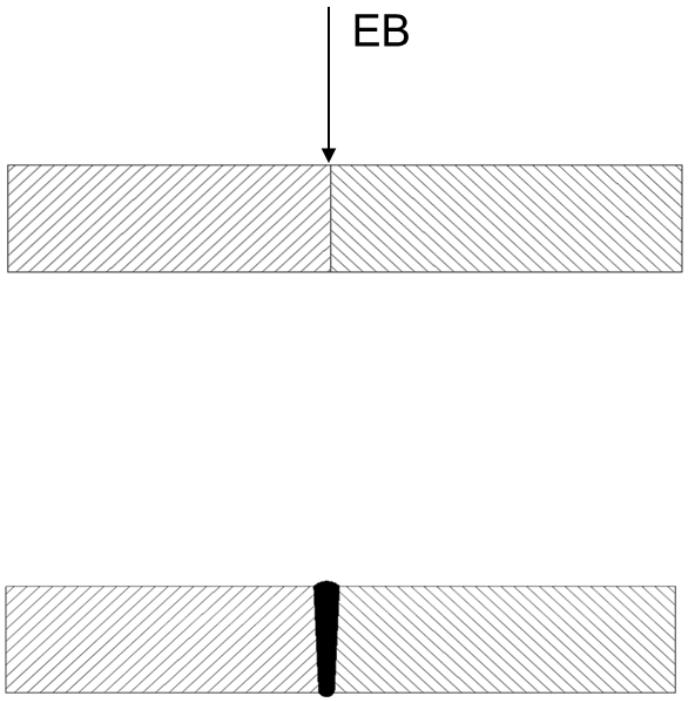
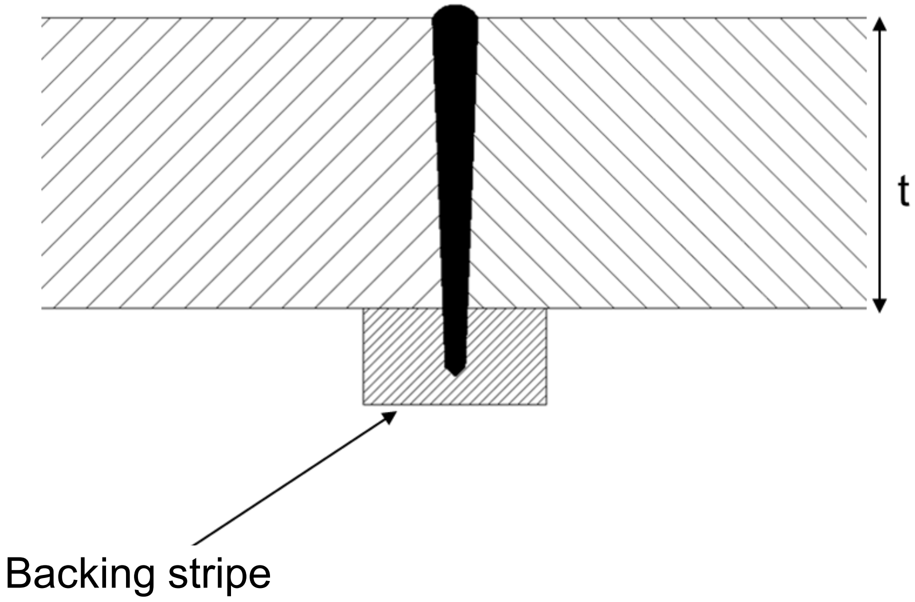
- butt weld: full penetration vs. partial penetration

Full penetration



Partial penetration



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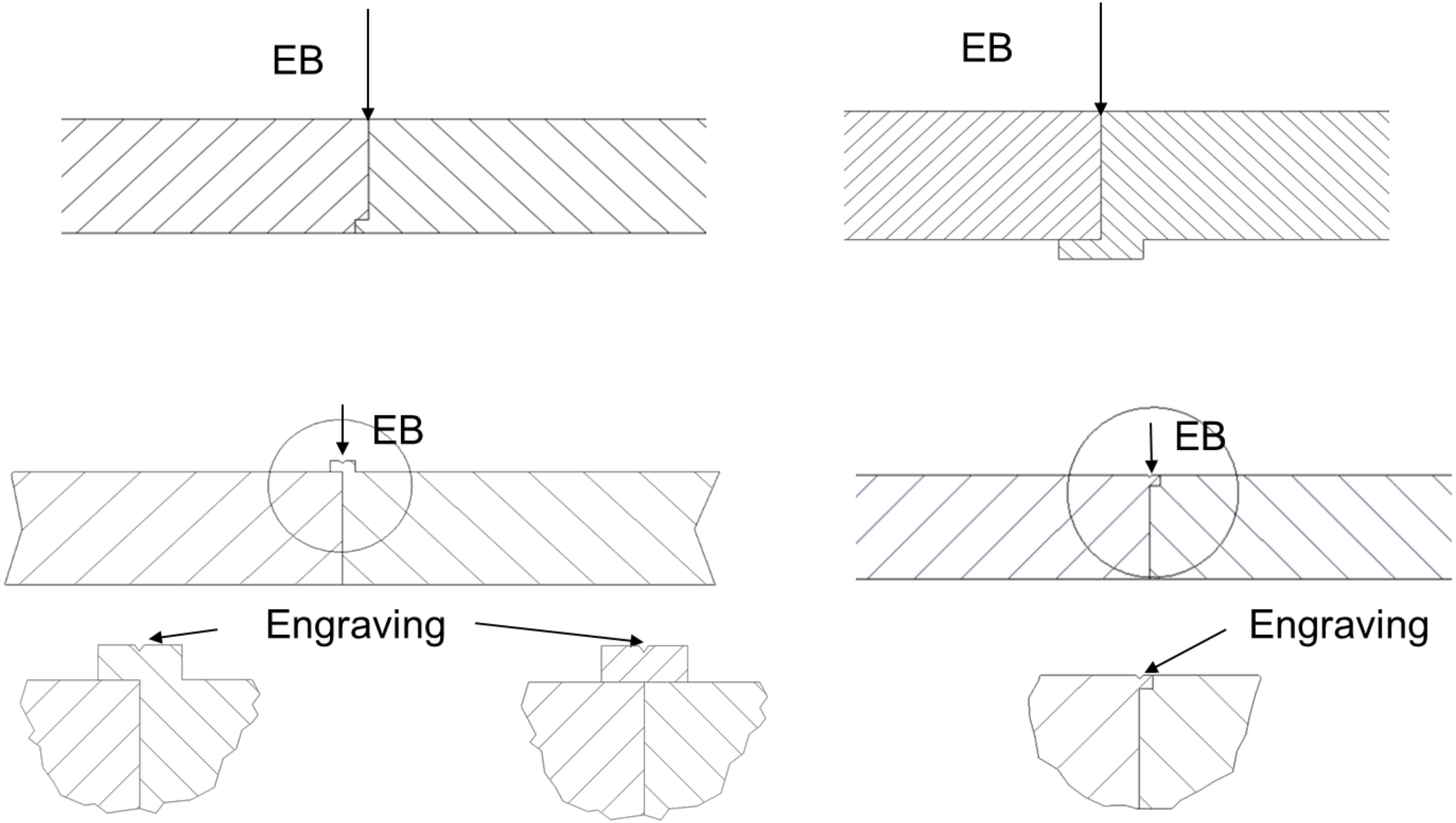
- Centering lips: non-beam side (favorable) vs. beam side



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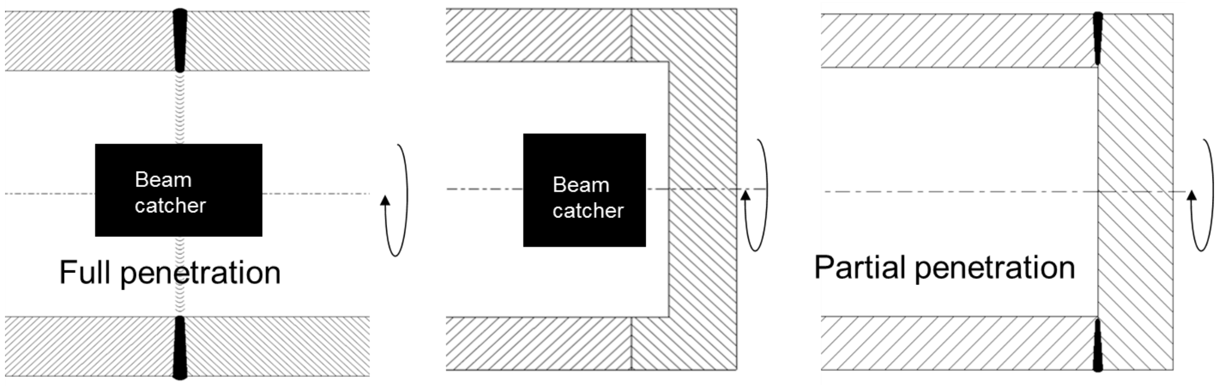
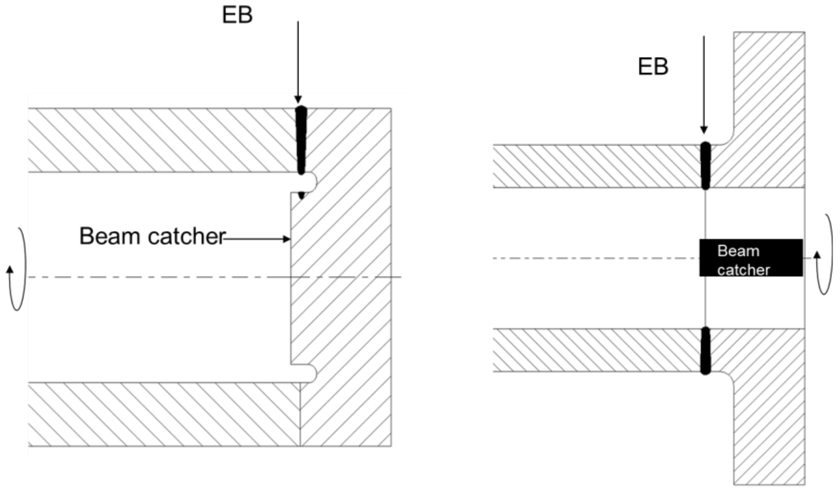
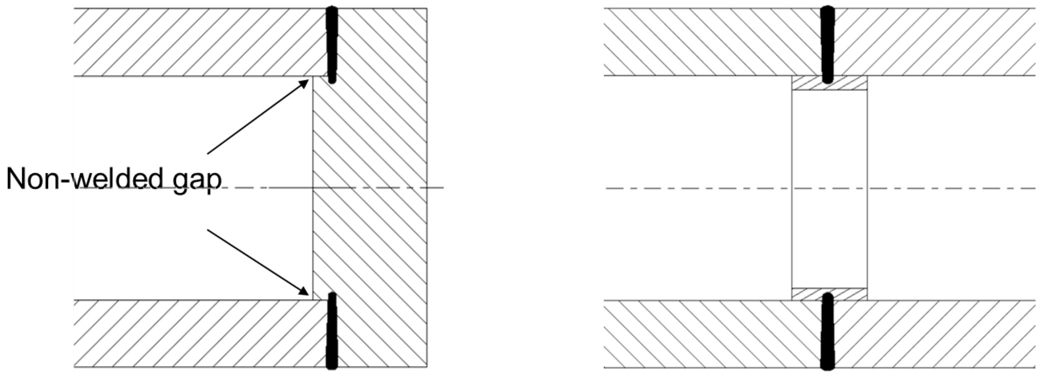
- Radial welds: allows free expansion and shrinkage





tube / flange connection



Design for Electron Beam Welding

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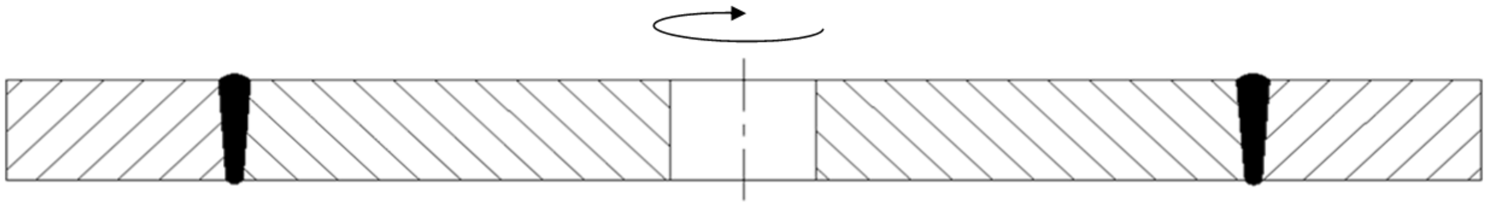
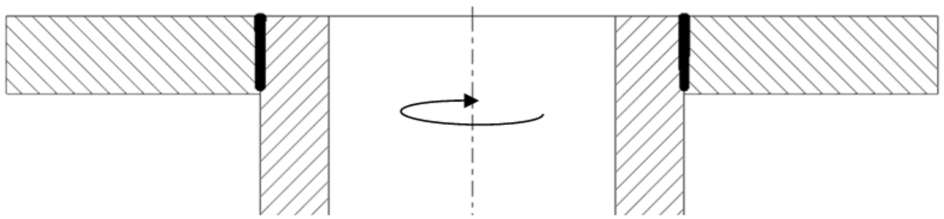
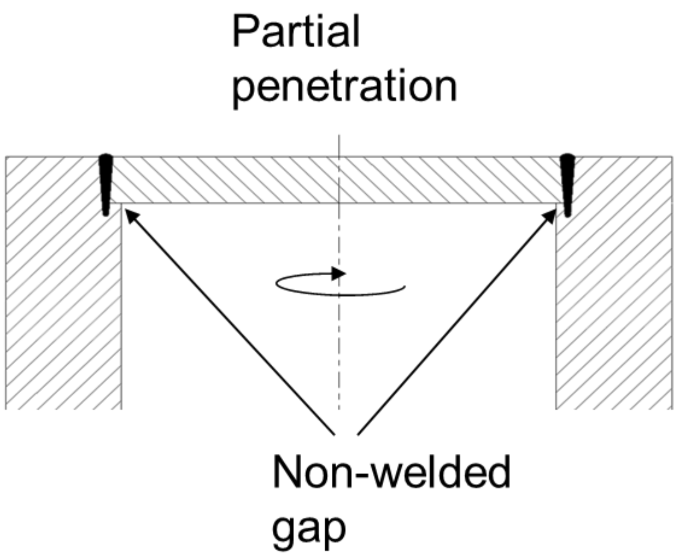
- Axial welds: restricted expansion and shrinkage



Full penetration

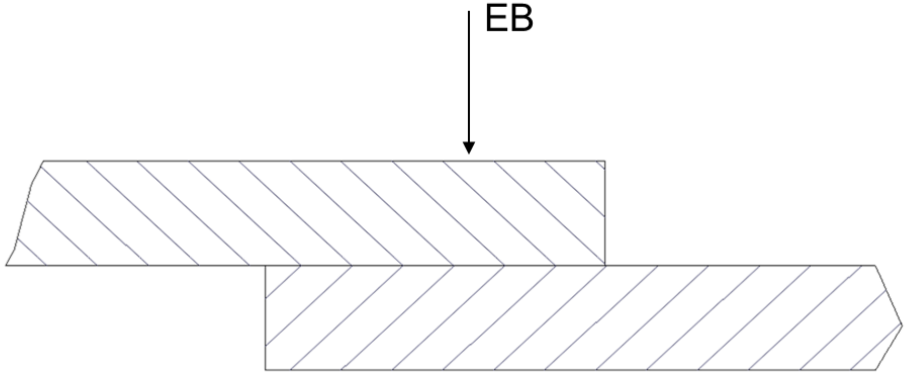


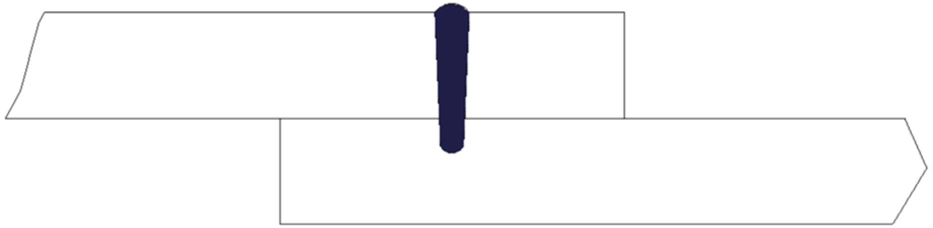
Tube / flange connection

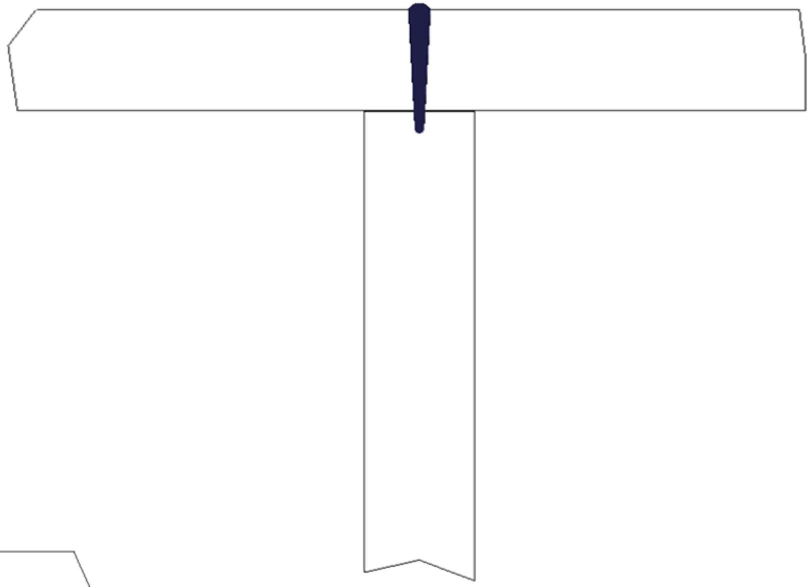


Design for Electron Beam Welding

- Lap welds: full penetration through first plate into second plate and T-joint welds







Design for Electron Beam Welding

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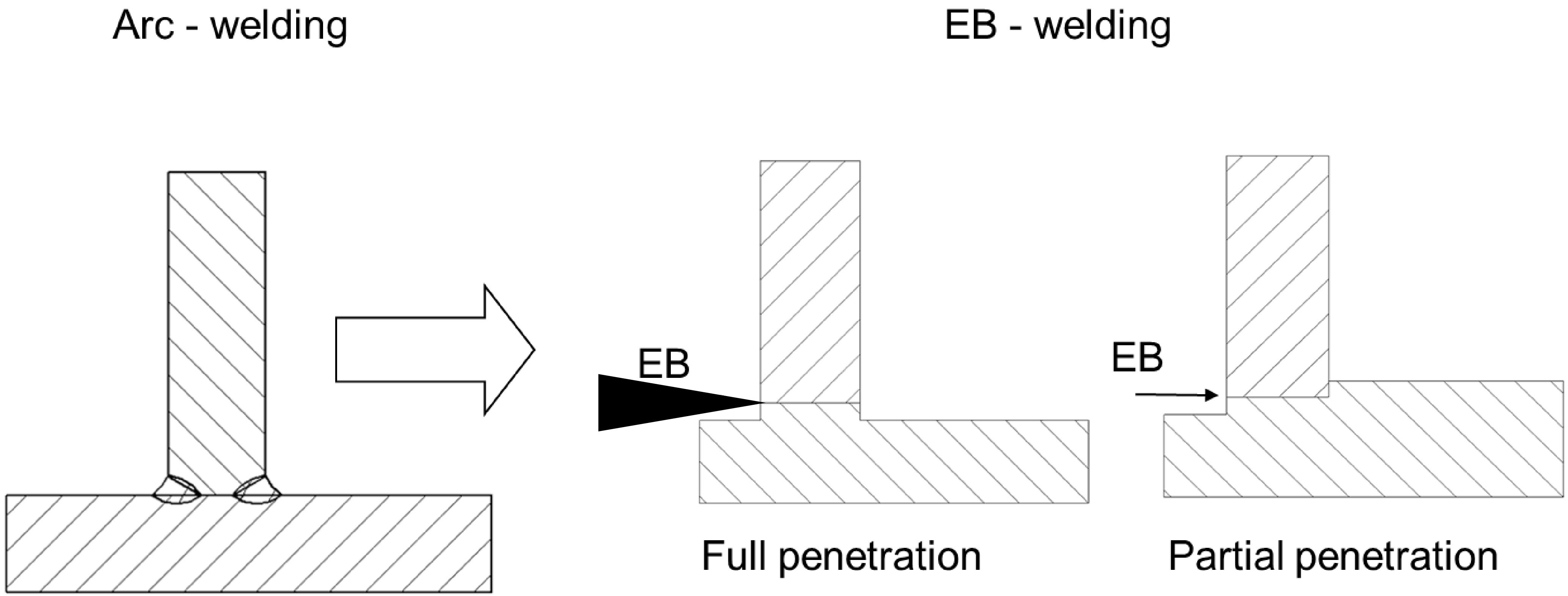
- Example: Design adoptions for EB-Welding



Thank you!

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September 2025

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