BUDAPEST UNIVERSITY
OF TECHNOLOGY AND ECONOMICS
FACULTY OF MECHANICAL ENGINEERING

Joining of plastics

Polymer Processing, BMEGEPTAGE3

Béla Zink, PhD, assistant professor

2021

DEPARTMENT OF
POLYMER
ENGINEERING

Joining

Joining is a technique of assembling two or more parts (towards a final product)

Joining can be via:

- material
- shape
- force

Joining can be:

- releasable
- non-releasable

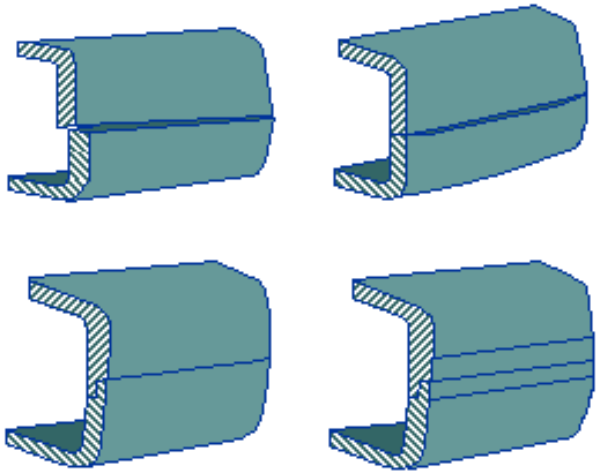
Joining of

- the same type of polymers (thermoplastic)
- different polymer materials
- different materials (e.g. polymer-metal)

Joining via force

Parts are joined via force:

- Threaded joint (bolted or screwed joint)
- Step joint
- Ring-clamp

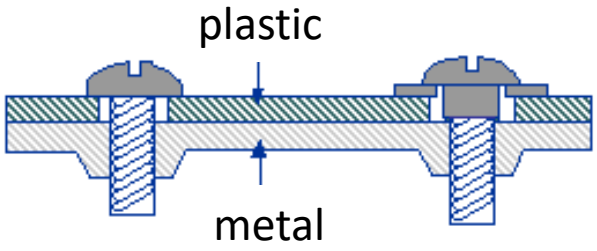


Parts are joined via shape:

- Snap fits
- Riveted joints

Parts are joined via material:

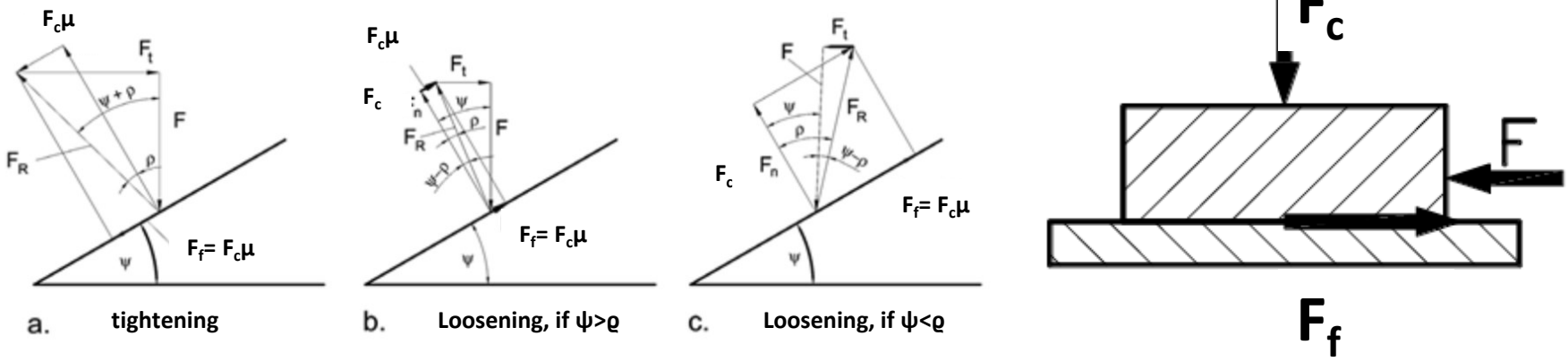
- Adhesive bonding
- Welding



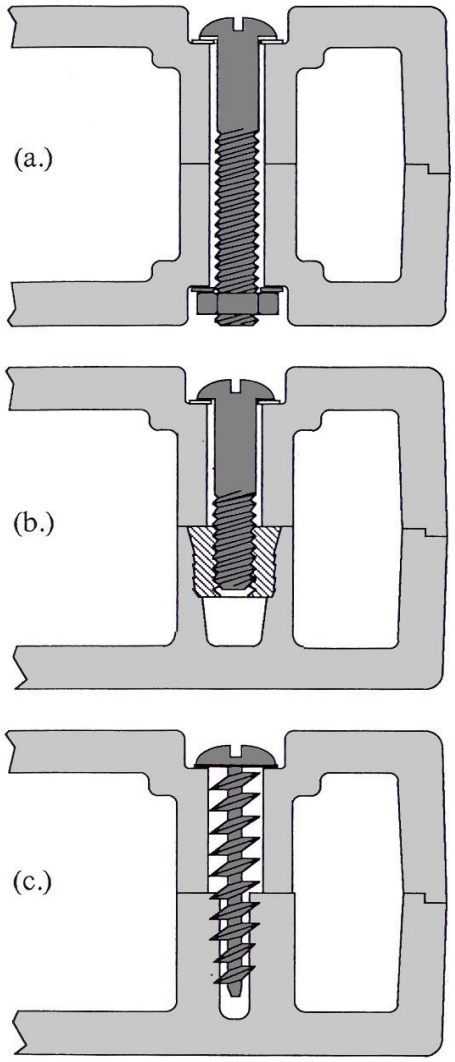
Joining via force

Parts are joined via force:

- There is friction between the parts due to force which ensures the shiftless linkage between the parts.
- The most important are bolted/screw joints
- Advantages: releasable, low tooling cost
- Disadvantages: Because of the stress relaxation and creep of polymers friction force can decrease thereby joining force will decrease); different expansion coefficient of metallic screw; difficult recyclability.



Joining via force

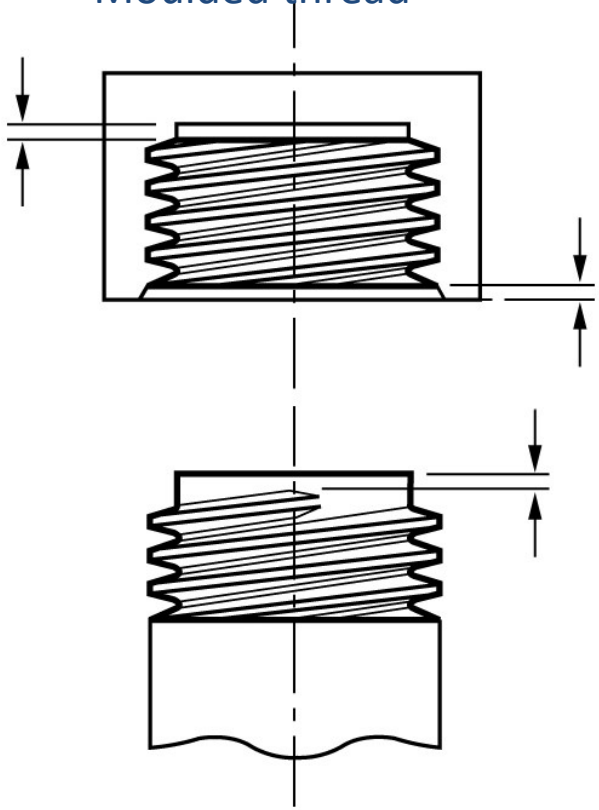


Screw + metric nut

Screw + insert

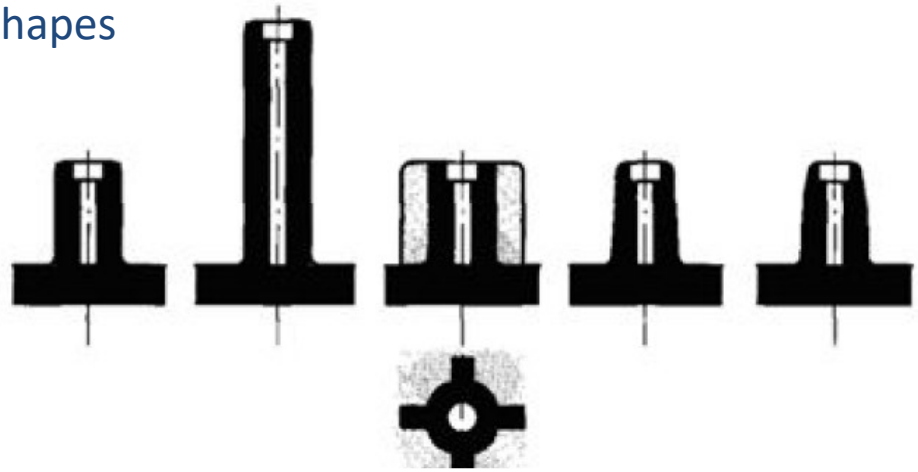
Self-tapping screw + polymer tube

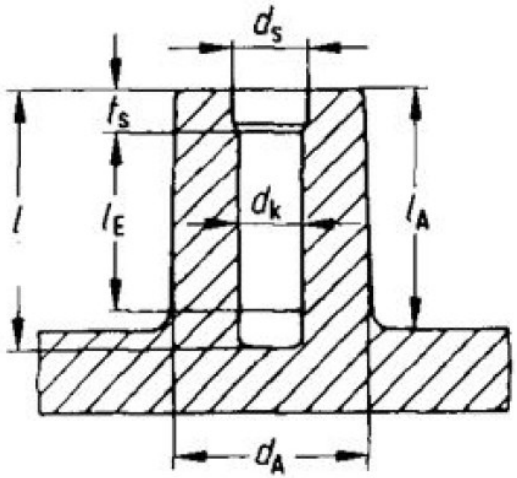
Moulded thread

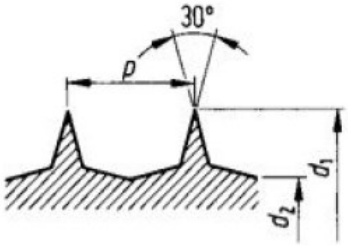


Joining via force

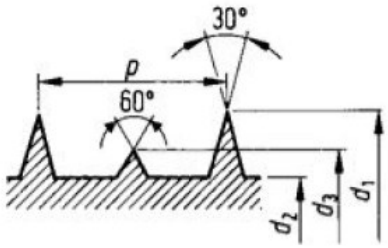
Tube shapes



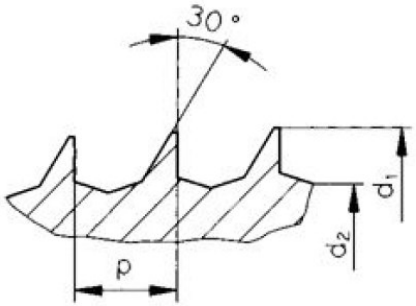




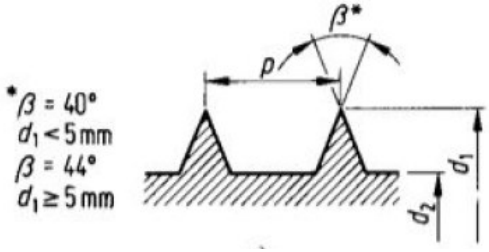
Thread angle = 30°



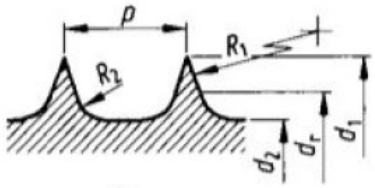
Double section



Duromer screw



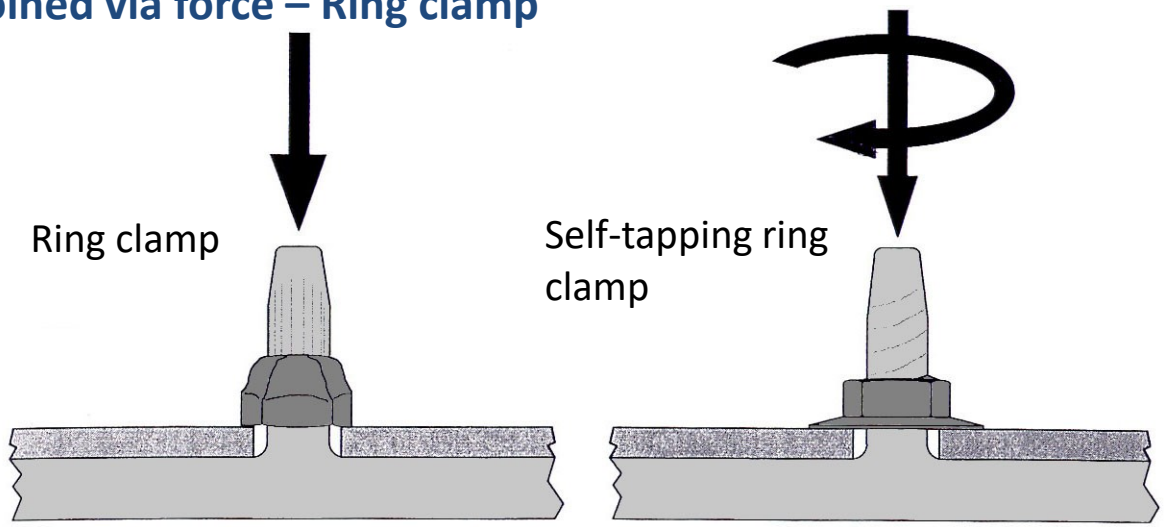
Sheet screw



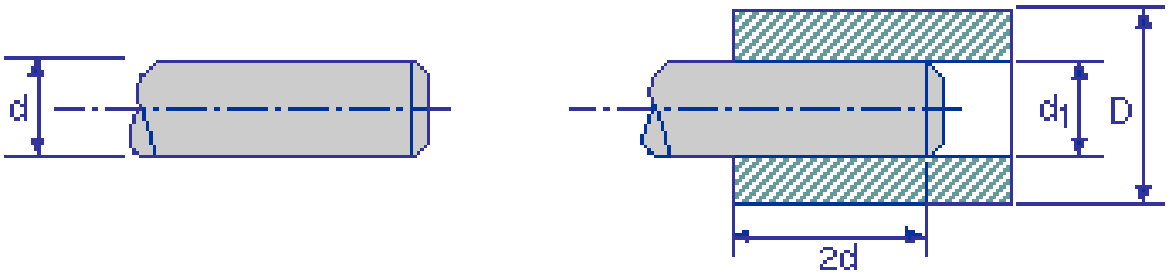
Polymer screw

Joining via force

Parts are joined via force – Ring clamp



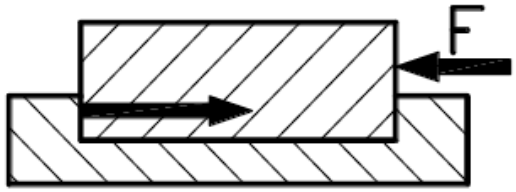
Step joint ($d>d_1$; overlapping: 3-5%)



Joining via shape

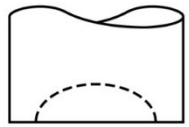
Parts are joined via shape:

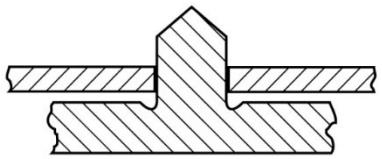
- Parts design (geometry limits the shift of the counterparts) ensures the joining.
- In the plastic industry the most important are the riveted joint and the snap fit joint.

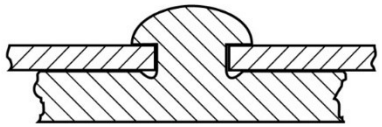


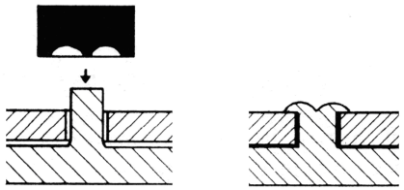
Riveted joint:

- Different materials can be joined (polymer/polymer; polymer/metal; etc.)
- Rivet forming with moulding of the material of one of the parts is widely used
- Advantages: fast and simple (cheap)
- Disadvantages: load carrying capacity is significantly lower than that of bolted joints. The positioning of the tool highly affects joining strength. Not aesthetic.
- The tool (mould) can be:
  - Cold tool
  - Hot tool
  - Cold tool wit hot air
  - Ultrasonic





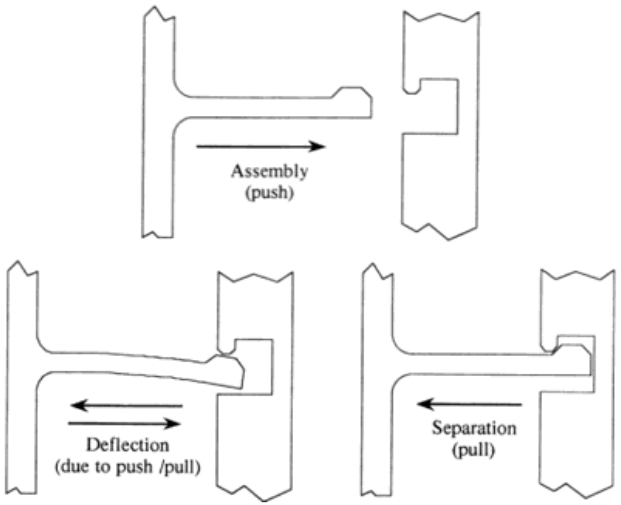




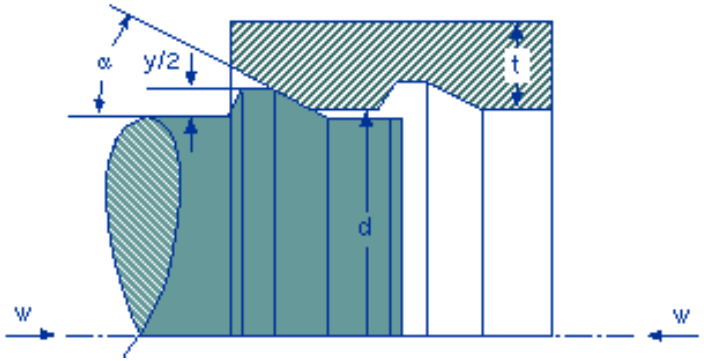
Joining via shape

Parts are joined via shape – snap fit joint:

- During joining the parts are assembled by overlapping, thereby one of the parts deforms. When the joint is completed the deformed part is again **undeformed (unloaded) and stress-free**.
- Snap fit joints can be classified as: Releasable, releasable with special tool, non-releasable.
- Advantages: quick and simple joining and there are no additional parts for joining.
- Disadvantages: It is economically feasible only for large series



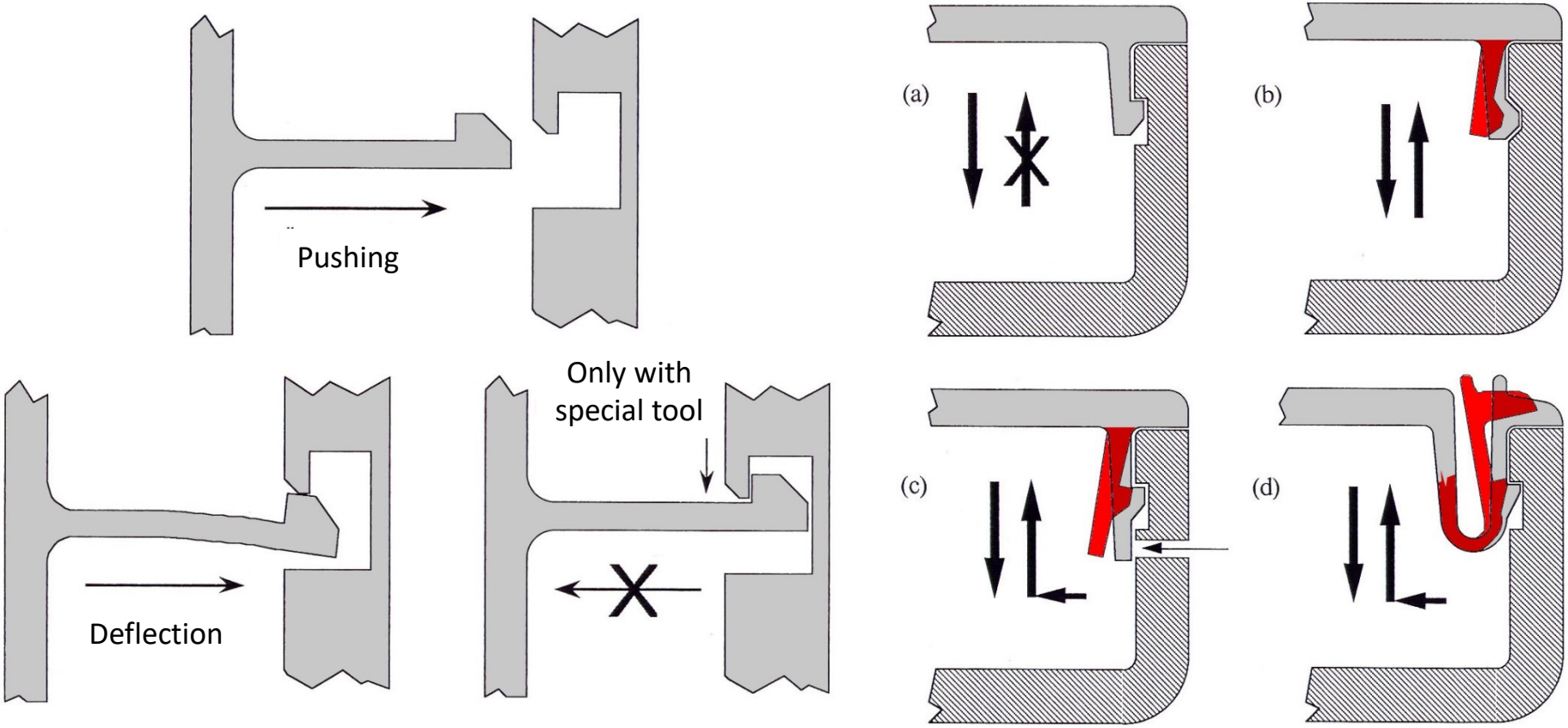
Cantilever-type



Annular-type

Joining via shape

Cantilever-type snap fit



Joining via material

Parts are joined via material layer:

- Joining is ensured by adhesion (surface connection) or by cohesive force (linkage between molecules, atoms)
- Glued (adhesive) or welded (cohesive) joint

Glued joint: joins two elements by applying adhesive between them. Joining is ensured by surface adhesion without modification of the joined parts.

- Advantages: large joining strength, different materials can be joined, large surface can be connected without residual stress.
- Disadvantages: it cannot be released non-destructively; the surface has to be thoroughly cleaned (surface treatment).
- Gluing mechanisms: mechanical joining (surface roughness), interdiffusion (macromolecule interlocking), adsorption (secondary bonds), chemical reaction (primary bonds).

Joining via material

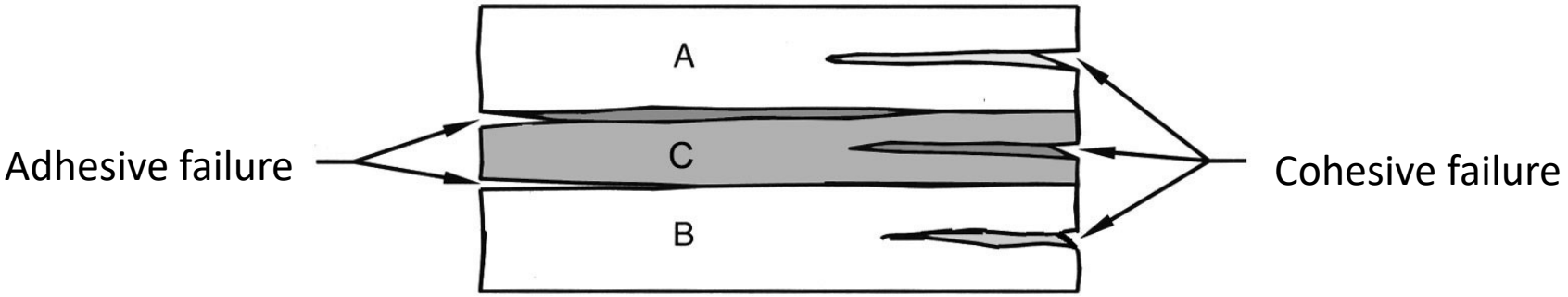
Glued joint

The strength of the glued joint is determined by:

- Strength of the adhesive and the components to be glued
- Adhesion between the glue and the surface of the components

A proper glued joint has approximately as large adhesion strength as the cohesive strength the joined parts have.

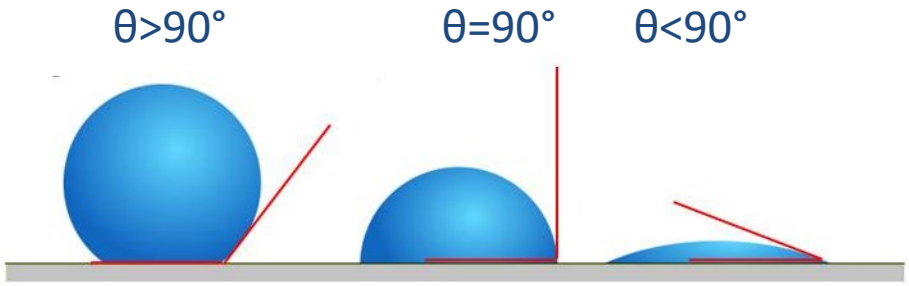
Failures of glued joint:



Joining via material

Glued joint

- Polymers cannot be glued with the same adhesive, at the same quality, with the same gluing technique.
- The type of adhesive and joining technique depends on the chemical structure (apolar, polar) and mechanical behaviour of the polymers.
- Wettability of the surface to be glued is essential for successful gluing. (contact angle, θ). For molecular contact between adhesive and polymer, good wettability is necessary.
- The roughness of the surface to be glued is also very important.
- Solubility of the polymer by the adhesive (additional diffusion)
- When the adhesive is selected, the mechanical properties of the parts to be glued have to be considered.



Joining via material

Glued joint

- Homogenous (only adhesive)
- Inhomogeneous (with reinforcement)
- Complex (adhesive + mechanical joining – e.g. rivet)

Main technological steps:

- Surface treatment: cleaning, roughening (mechanically - polishing, chemically - etching), oxidation – flame treating, corona treating, plasma treatment
- Preparation of adhesive: dosing and mixing of components; stirring of adhesive, incorporation of fillers/reinforcements
- Spreading of adhesive onto the surface (manual or automated)
- Alignment and fixing of the parts
- „Hardening” of adhesive (solvent removal, cooling, curing)
- Finishing steps: post annealing, removal of unnecessary adhesive, covering the glued joint with a protective layer

Joining via material

Welding

- Heat and pressure are applied simultaneously
- With or without additional material
- Only compatible thermoplastic polymer materials can be welded. Cohesive connection is formed under pressure at an elevated temperature (melted polymer).

Four requirements of welding:

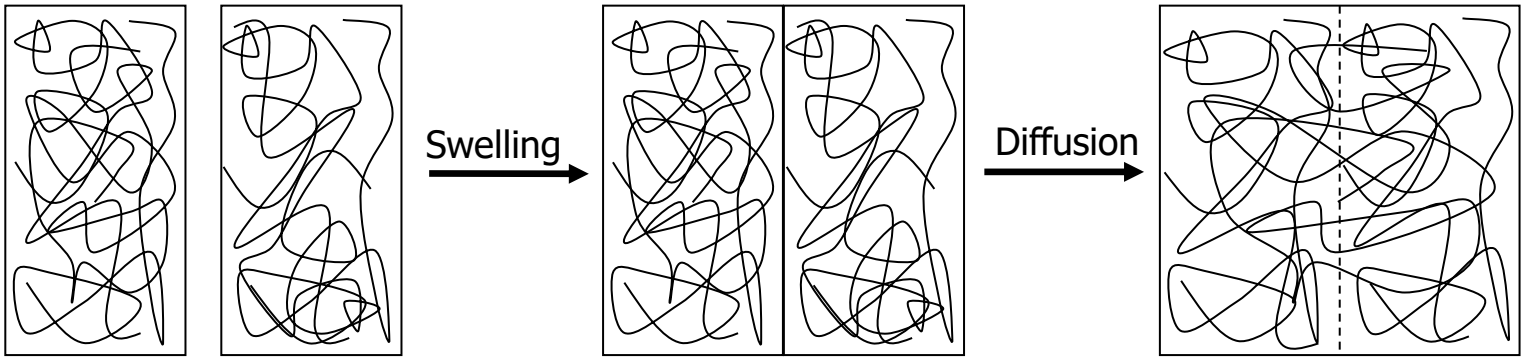
- Equivalent structures of molecules.
- Temperature guarantees the proper viscous and elastic physical states within an optimal period.
- To keep pressure high enough to produce the required distance between surfaces to be welded.
- Cooling the welded joint to reach the state of load carrying.

Joining via material

Welding- diffusion

The quality of the welded joint (strength of the joint) depends also on the mechanism between the contacting surface of the melted macromolecular materials (self-diffusion). Macromolecules, their segments and chainends bond together through the interface.

Welded joints can be characterized by the Joint Efficiency Factor (Strength of welded joint / strength of the raw material).



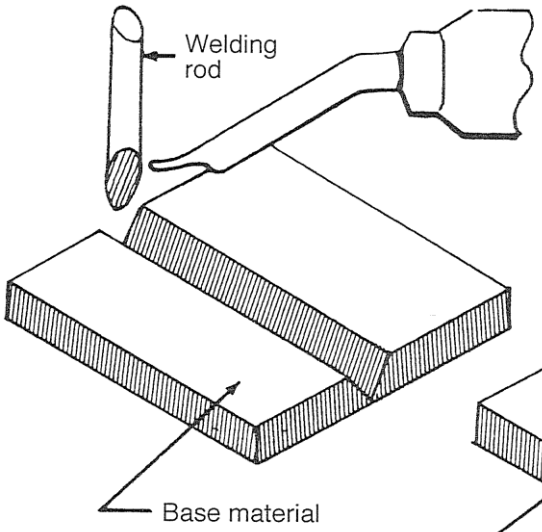
Welding techniques can be classified according to the method of heating:

- Heat convection (external heating)
- Radiation (internal heating)
- Mechanical (internal heating)

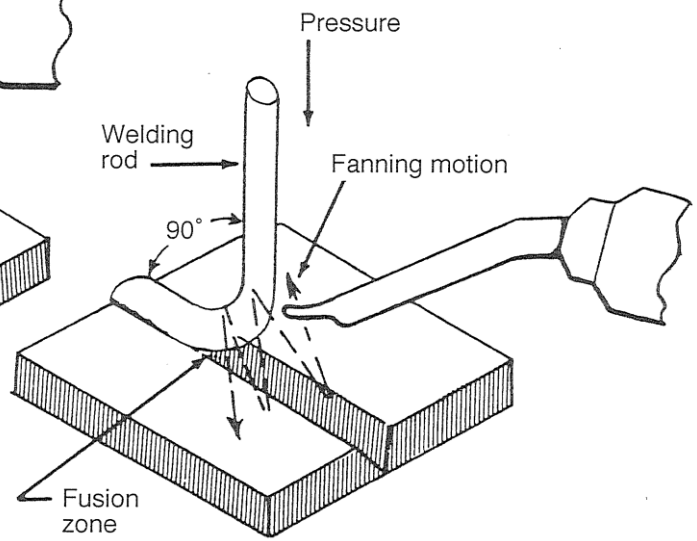
Joining via material

Welding (heat convection)

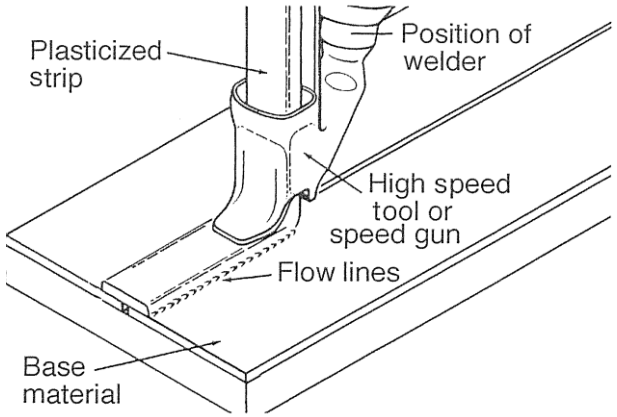
Hot air welding: The parts and the welding rod are heated by hot air. The heat transfer medium is usually air but can also be CO_2 or N_2. Air temperature is 200…400°C, the volume flow rate is 25…100 l/min. Welding speed is 30…200 mm/min. It is a manual technique. Its advantage is its relative low technological cost and ease of installation. It is used for small series, or for a large product or for repair.



Starting weld



Welding

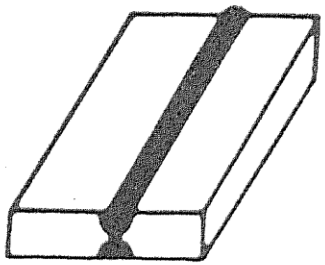


High speed welding

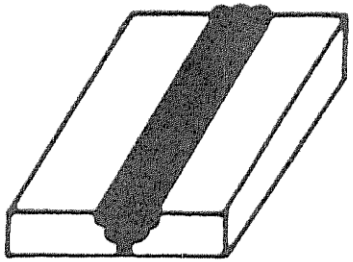
Joining via material

Welding (heat convection)

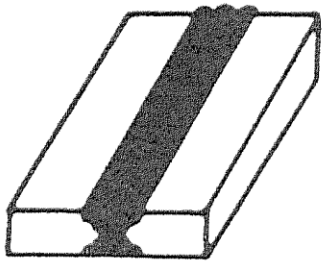
Hot air welding: weld types



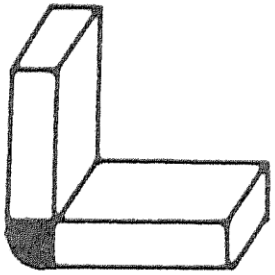
Double-V
butt weld



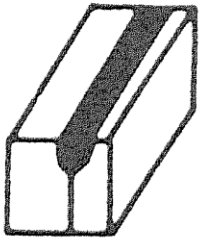
Multiple bead
single-V butt weld

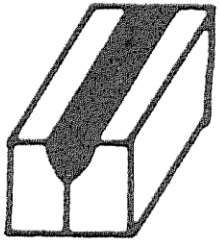


Multiple bead
double-V butt weld

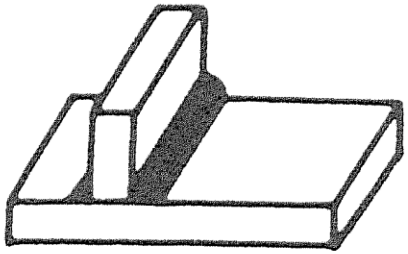


Corner weld

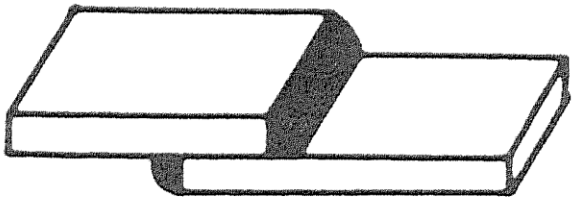




Eagle welds



Fillet weld

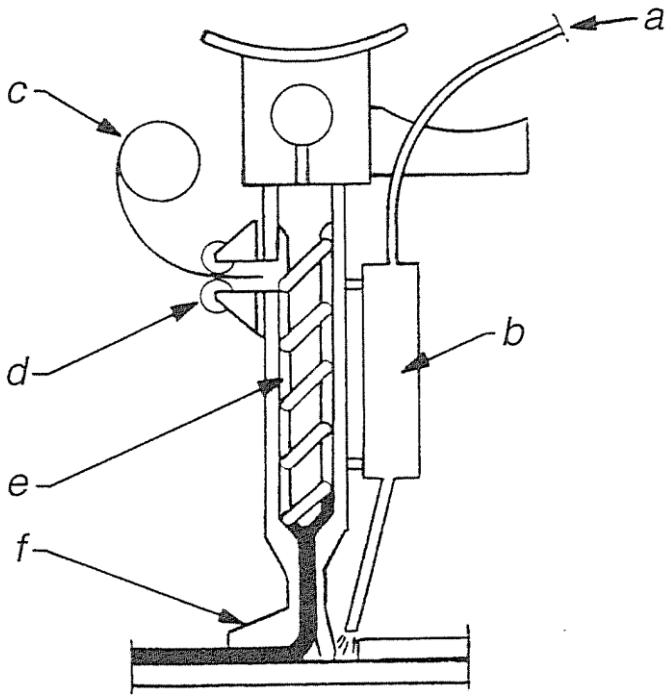


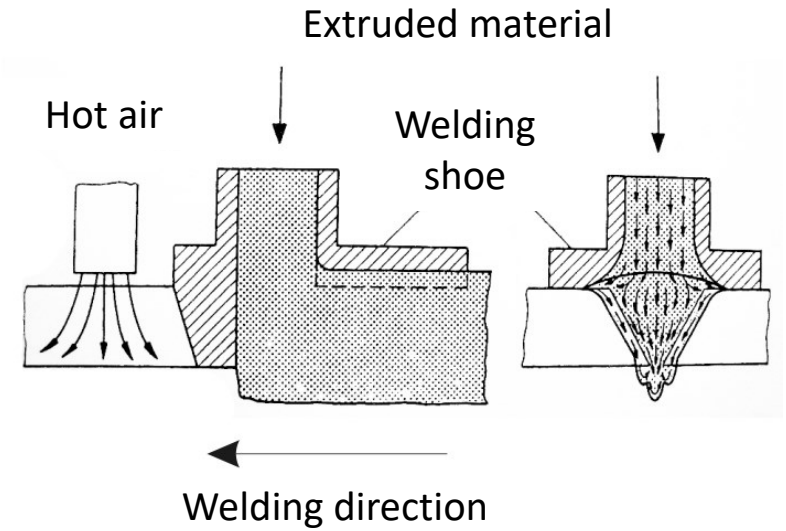
Lap fillet weld

Joining via material

Welding (heat convection)

Extrusion welding: For large-volume seams. It is used when hot air welding becomes uneconomic (over 6-8 mm of thickness). It is a manual technique.



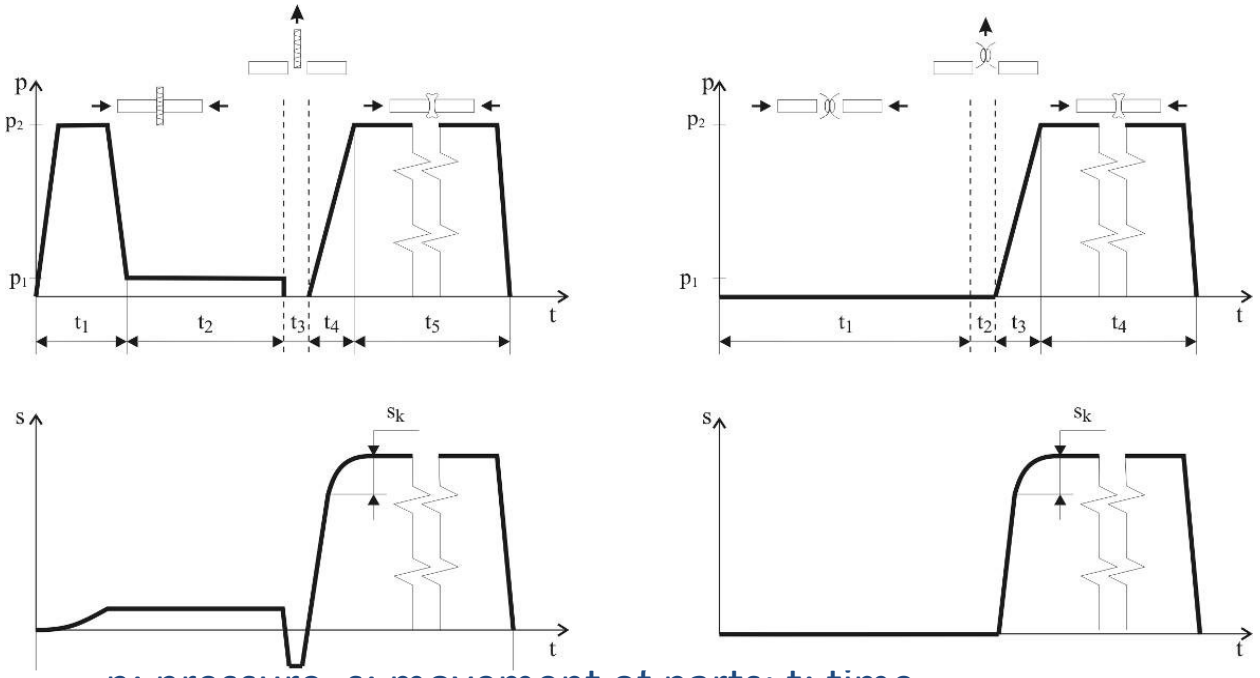


a: air supply; b: hot air device; c: wire reel (as shown) or granulate hopper, d: wire forward feed; e: small extruder; f: welding shoe.

Joining via material

Welding (heat convection)

Hot-plate (hot die) welding: For large series production. The cleaned surfaces of parts are pressed or approached to the hot plate and later the hot plate is removed and the parts to be welded are pressed together. It is especially suitable for large-volume products and/or if airtight closure is required (for pipes, fuel tanks, etc.). There are contact (left) and contactless (right) methods.

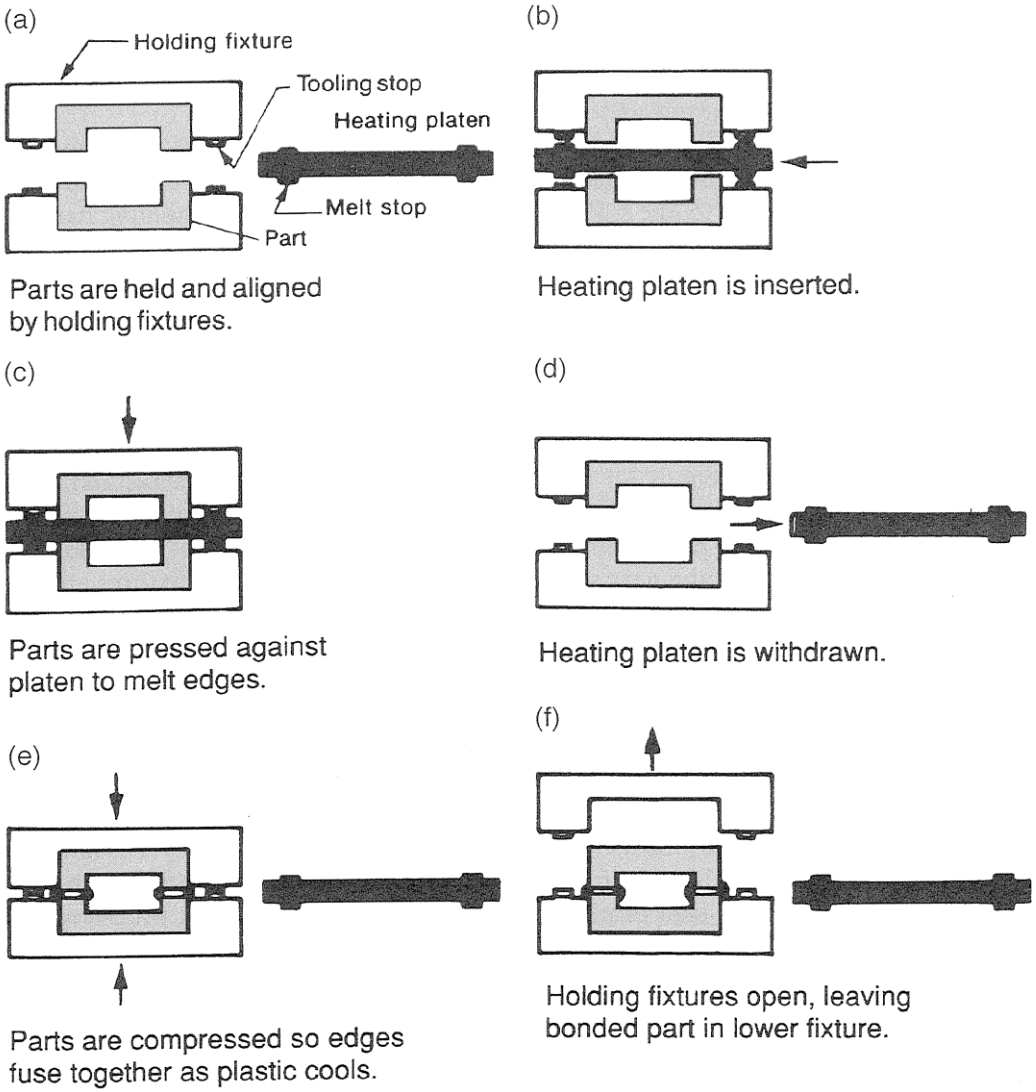


p: pressure, s: movement of parts; t: time

Joining via material

Welding (heat convection)

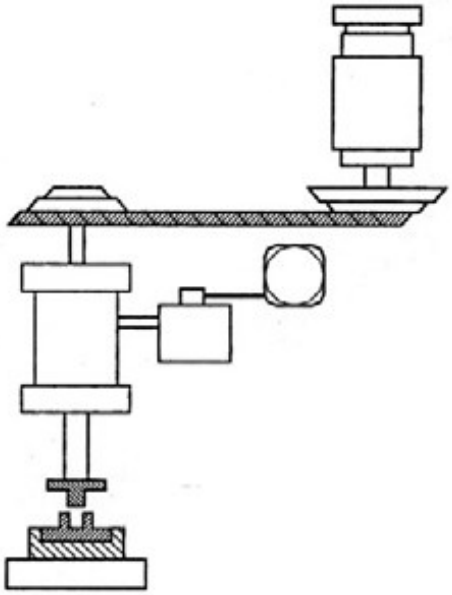
Hot-plate (hot die) welding

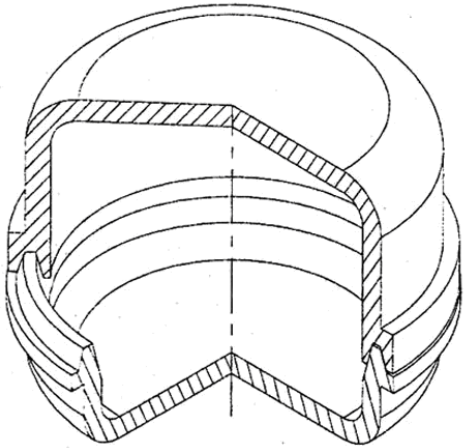


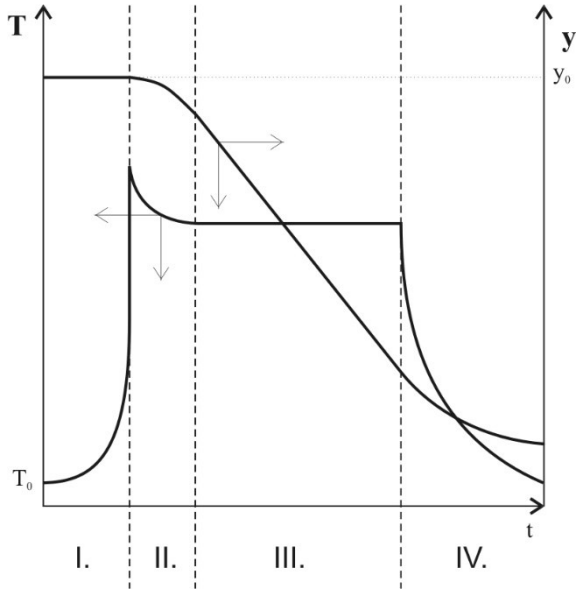
Joining via material

Welding (mechanical)

Spin welding: One of the parts is rotating at a high speed (50…150 m/s), and is pressed to the other fixed part (p=1…2 MPa). Heating is ensured by the friction between the two parts. When the surface is melted, the rotation is stopped and the welded parts cool under pressure. The technique is well and easily controlled, only a simple device is required.







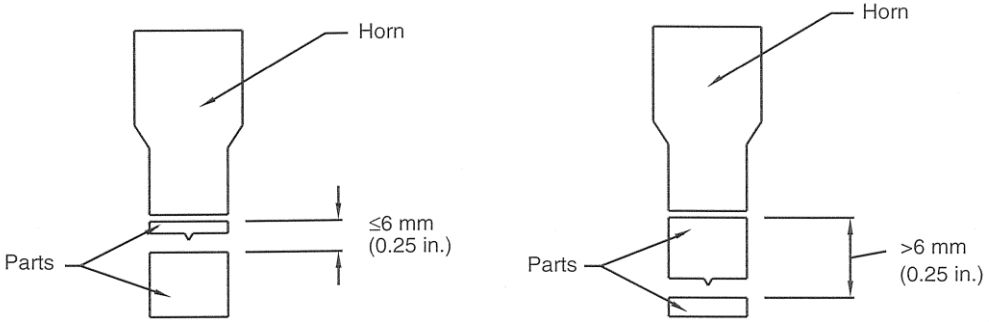
Joining via material

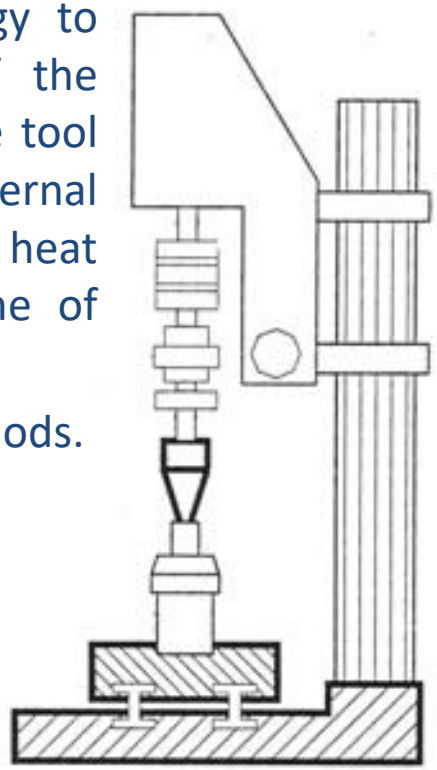
Welding (mechanical)

Ultrasonic welding: Damping capability of the polymers is exploited.

The parts to be welded are matched and the upper part is loaded with vibrations of 20-40 kHz frequency. Its operating principle: The ultrasonic generator converts the line power and supplies high-frequency electrical energy to the converter. The converter changes electrical energy to mechanical vibrations. The booster modifies the amplitude of the vibration (increase/decrease) supplied to the horn. The horn is the tool that transmits the vibration to the part. The vibrations cause internal friction in the polymer parts at the molecular level and result in local heat development. The developed heat can be increased by the time of excitation. After cooling, the welded joint is ready.

There are near field (left) and far field (right) ultrasonic welding methods.

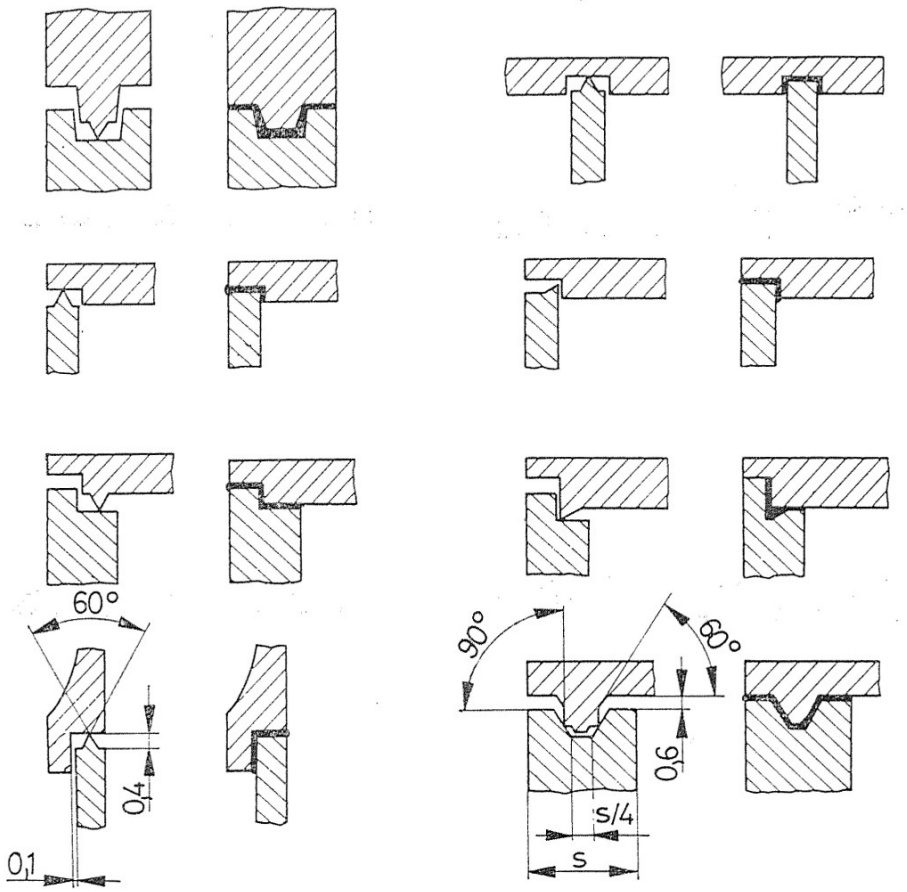


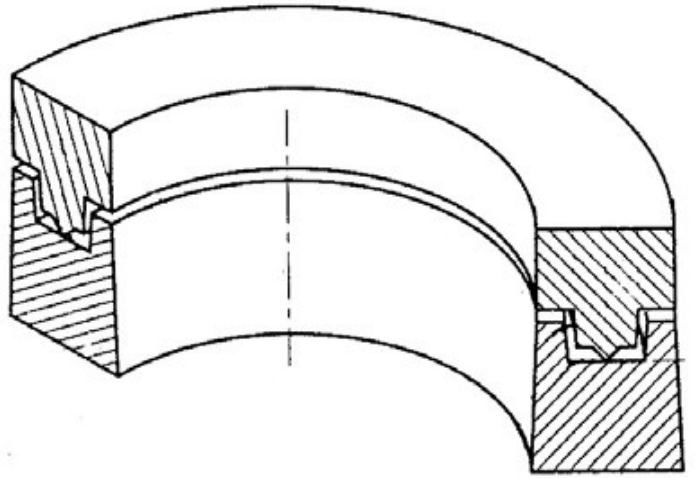


Joining via material

Welding (mechanical)

Ultrasonic welding: Part design rules





References

References:

- J.R. Wagner Jr., E.M. Mount III, H.F. Giles Jr.: PDL Handbook Series, Extrusion: The Definitive Processing Guide and Handbook. Elsevier Inc., Oxford, 2014
- D.V. Rosato, A.V. Rosato, D.P. DiMattia: Blow Molding Handbook. Hanser, Munich, 2004
- G.L. Beall, J.L. Throne: Hollow Plastic Parts: Design and Manufacture. Hanser, Munich, 2004
- C. Rauwendaal: Polymer Mixing: A Self-Study Guide. Hanser, Munich, 1998
- J.L White, A.Y. Coran, A. Moet: Polymer Mixing: Technology and Engineering. Hanser, Munich, 2001
- J.L. Throne: Technology of Thermoforming. Hanser, Munich, 1996
- P. Schwarzmann: Thermoforming: A Practical Guide. Hanser, Munich, 2001
- W. Michaeli: Plastic Processes: An Introduction. Hanser, Munich, 1995
- J. Rotheiser: Joining of Plastics. Handbook for Designers and Engineers. Hanser, Munich, 1999
- Internet

BUDAPEST UNIVERSITY
OF TECHNOLOGY AND ECONOMICS
FACULTY OF MECHANICAL ENGINEERING

Thank you for your attention!

DEPARTMENT OF
POLYMER
ENGINEERING