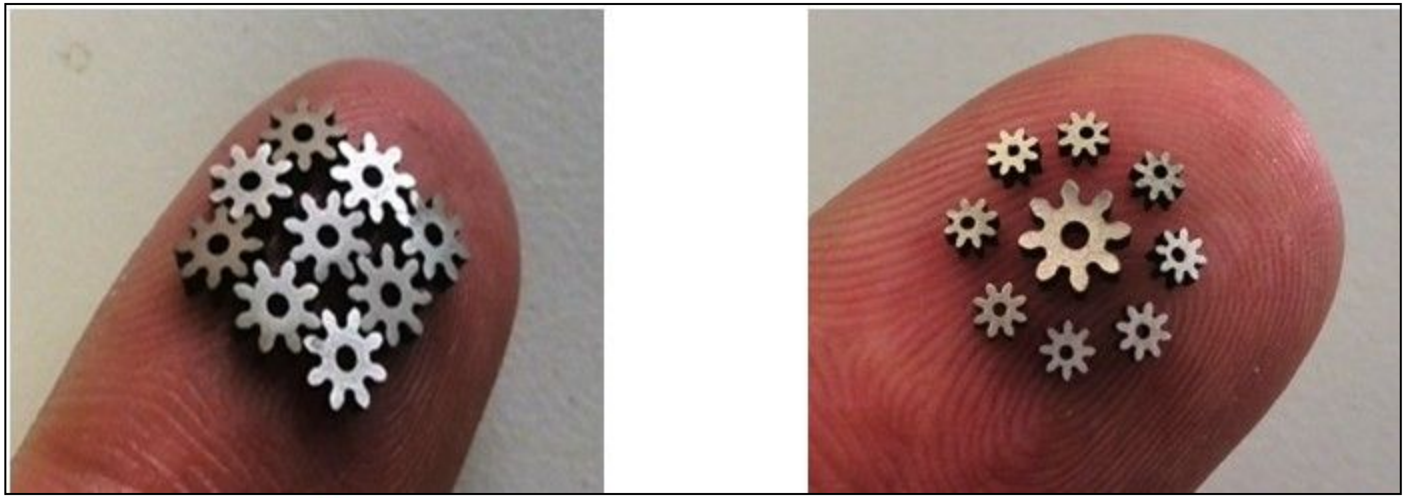
Micro Forming



Micro Forming

- Micro-forming is a production of parts or structures with at least two dimensions in the sub-millimetre ranges and which are formed from metal sheets of 10 to 300 micro meters of thickness.

- Bulk micro-forming – rolling, forging, extrusion, cold forming, cold forging etc.
- Sheet metal micro-forming – piercing, blanking, bending, deep drawing etc.

Need for micro forming

- Manufacture of micro parts with advanced LIGA and MEMS process offers high accuracy and bulk productions, but cost are comparable high and number of different materials is limited

- Manufacturing of micro components with conventional micro tools and with non-conventional process such as lasers, ion beam machining etc are accurate but expensive and have very low production rates

- Micro forming is an appropriate technology to efficiently produce large number of micro parts at low cost to fulfil the large demand of micro electronic parts

Features of Micro-Forming

- Characteristics of Micro-forming
  - high productivity,
  - low cost and good quality of the formed parts,
  - provides a promising approach to fabricating metallic micro parts.
- Challenges in micro forming machines:
  - Higher demands on positional accuracy,
  - Higher velocity
  - High production rates/ mass production

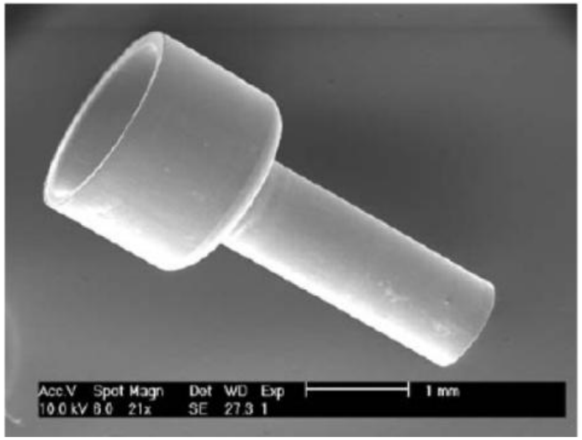
Challenges in Forming processes

Forming process:

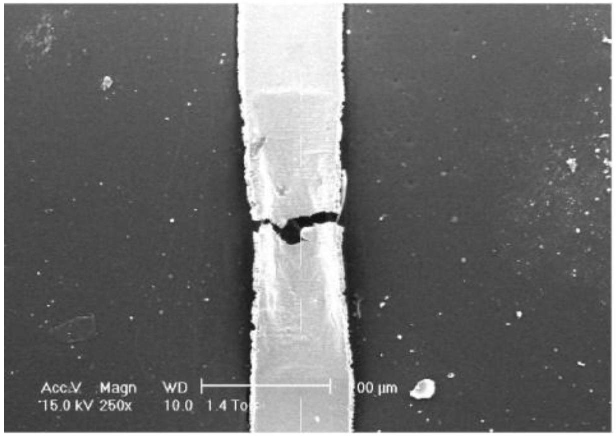
- Know-how for bulk parts cannot be used;
- turn/cast necessary;
- low production rates/high costs.

Reliability:

- reduced reliability;
- unexpected fracture; can lead to security problem.



Small axi symmetric part □18 step process

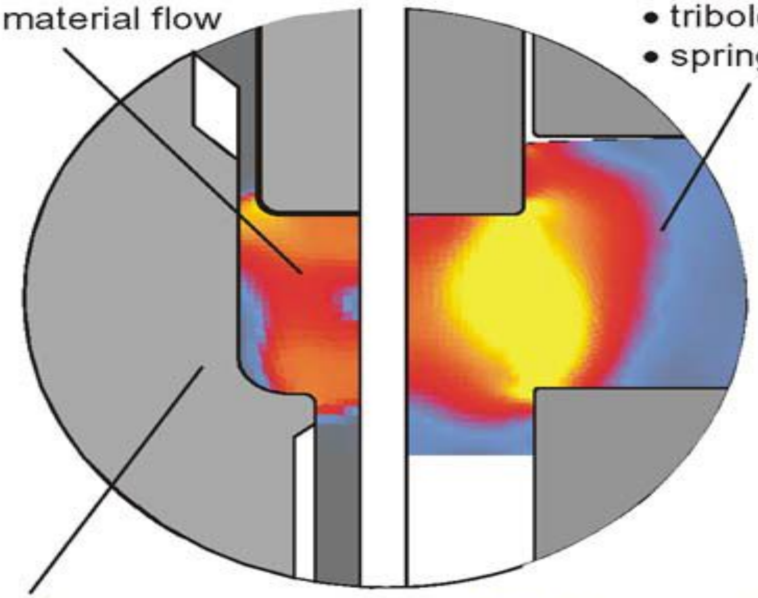


Airbag sensor: inflate start without accident

Challenges in Microforming

Material
- flow stress
- anisotropy
- ductility
- forming limit
- material flow

Processes
- forming forces
- accuracy of parts
- simulation
- scatter
- tribology
- springback



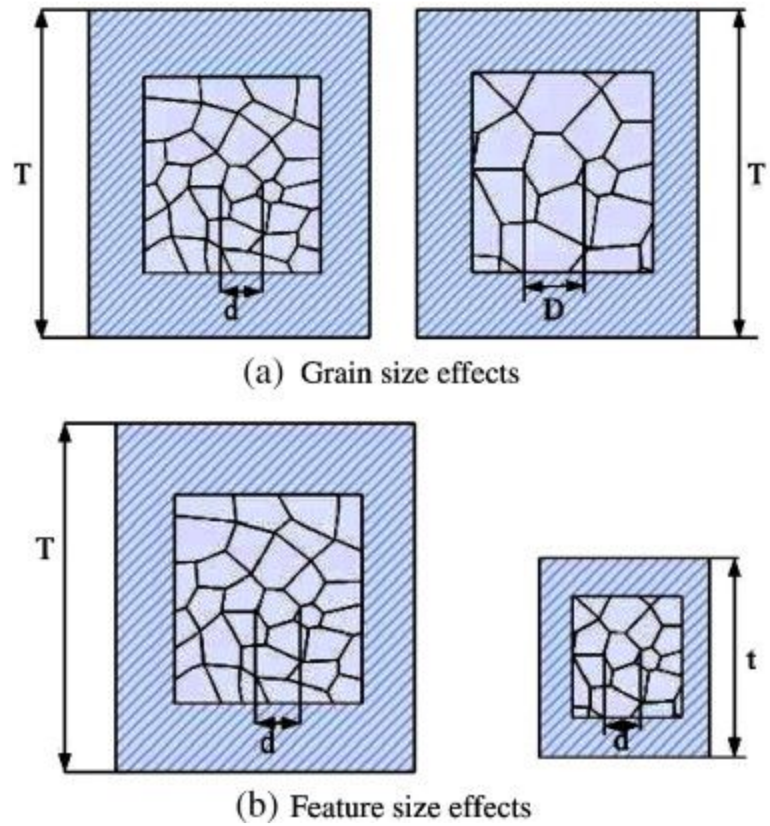
Tools
- tool production with advanced and new technologies
- tool materials
- tool accuracy
- laser as tool

Machines and equipment
- drives
- automation
- new handling concepts

Material behavior during micro/meso-forming process

- In metal micro/meso-forming process, the material behavior is influenced by the grain size, grain orientation and feature size.

- The most common used parameter to describe the material behaviour is the **flow stress curve**, because it determines the forming force, the load on the tools, the local flow behavior and thus the filling of the die cavities.

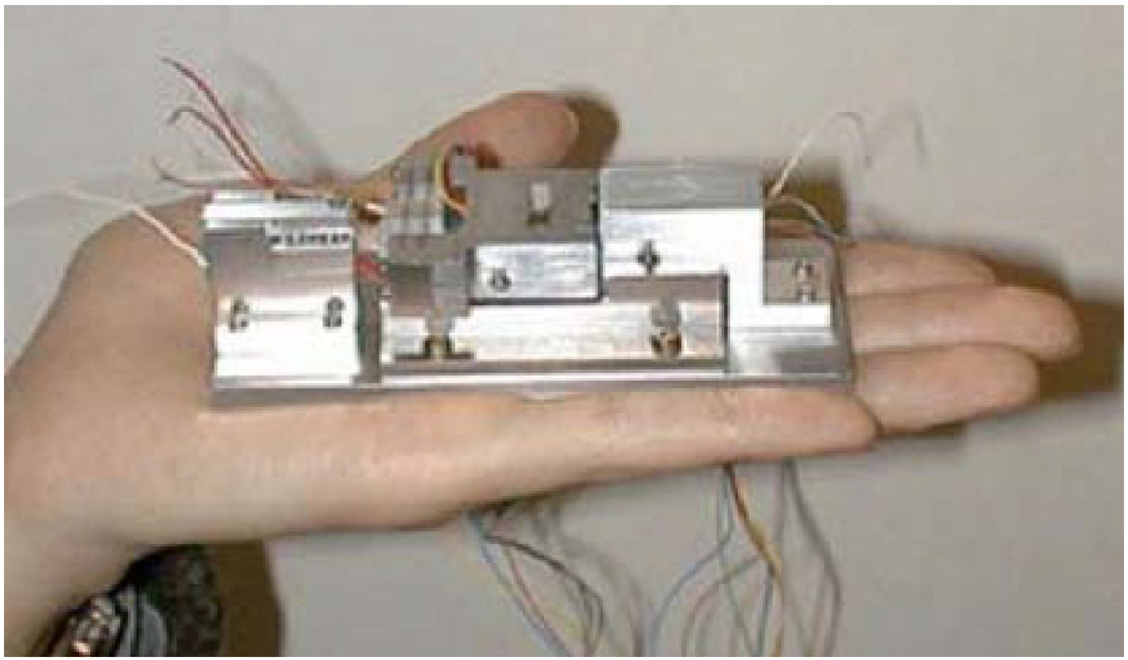


Grain size effects and feature size effects with the decreasing of the scale

Development of Micro-forming

- Rapid development of micro electro mechanical system (MEMS) and micro system technology (MST), a significant progress has been made in the fabrication of micro parts via various methods
- In 1990 T. Maeda, proposed the development of super micro precision press machine, which gives start to basic research in micro-forming.
- Development of the advanced micro-manufacturing technologies for fabrication of such micro parts has thus become a critical issue e.g. micro screws, lead frames, pins for IC-carriers, fasteners, etc.

Micro-machine for superplastic extrusion for forward extrusion of a microgear shaft of 10 micro meters



Saotome, Y.; Iwazaki, H., Gunma University, Maebashi, Japan (2000)

Difference between macro and micro forming

- Technological differences:
- In micro-forming a 3 axes CNC machine with a high positioning precision is needed
- The process must be conducted in a controlled atmosphere, pressure and temperature must be controlled.
- The support tool must be manufactured with high precision tolerances.
- In micro-forming, the advance speed of the tool must be lower than in conventional forming because the friction is highly increased.
- The forming tool size, in microform, is similar to the micro structural grain of the metal sheet alloy.

Process differences:

- In micro-forming the sheet metal has reduced formability.

- The grain size effect should be taken into account in the metal formability.

- In micro-forming, the microstructure of the sheet metal has a big influence on the forming process and capabilities.

Material for further reading

1. Yi Quin, Micro Manufacturing Engineering and Technology, 2011, CH 6,7,8, 9 and 10

2. F. Vollertsen, Z. Hu, , H.Schulze Niehoff, C. Theiler, State of the art in micro forming and investigations into micro deep drawing, Journal of Materials Processing TechnologyState of the art in micro forming and investigations into micro deep drawing, Journal of Materials Processing Technology, Volume 151, Issues 1–3, 1 September 2004, Pages 70–79

3. F. Vollertsen , H. Schulze Niehoff, H. Schulze Niehoff, Z. Hu, H. Schulze Niehoff, Z. Hu, State of the art in micro forming, International Journal of Machine Tools and Manufacture, H. Schulze Niehoff, Z. Hu, State of the art in micro forming, International Journal of Machine Tools and Manufacture, Volume 46, Issue 11, September 2006, Pages 1172–1179

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Microforming

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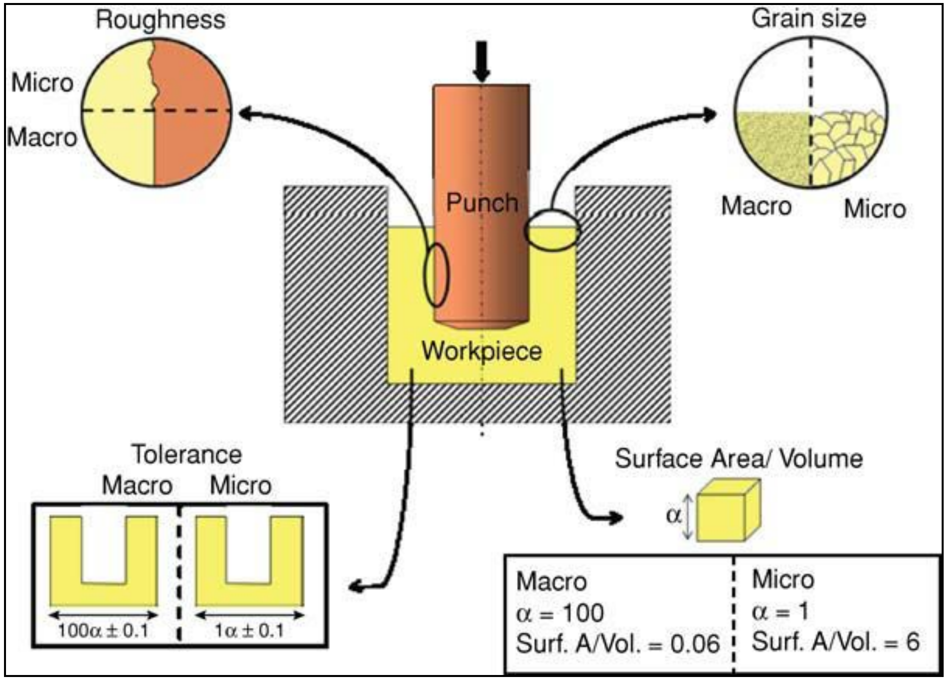
Micro Forming Processes

1. Bulk Micro forming
2. Forming of Micro-sheet metal components
3. Injection Moulding
4. Micro Hydro forming
5. Laser Assisted Micro forming

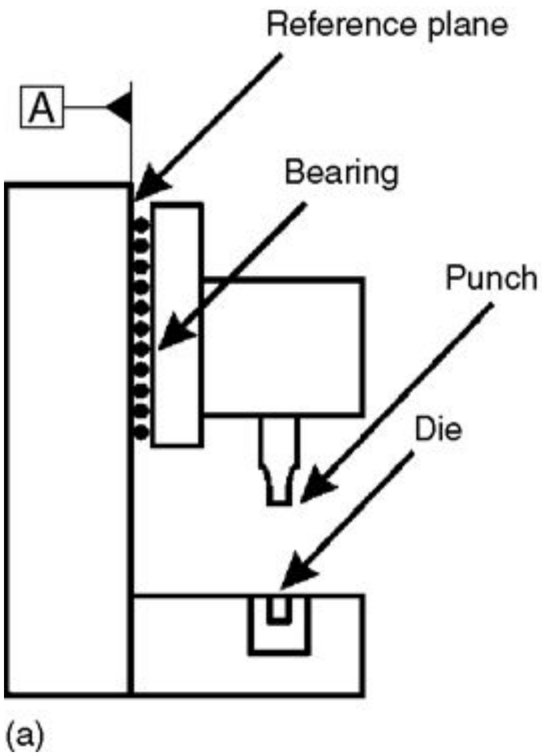
Micro forming

Size effects in micro-bulk forming

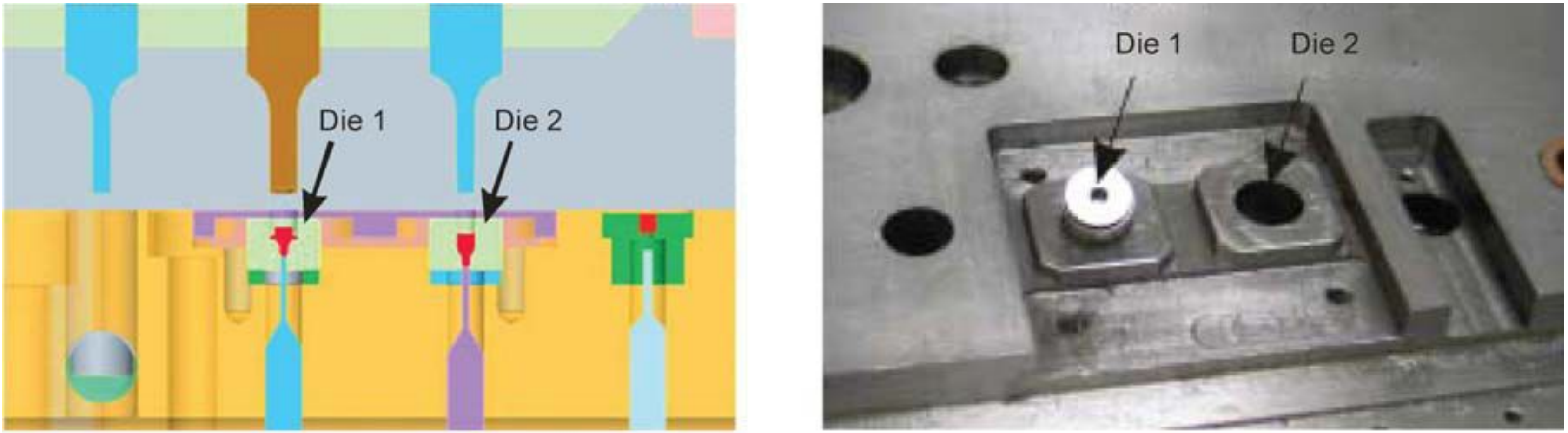
- Roughness scaling
- Grain size scaling
- Tolerance scaling
- Surface-to-volume ratio



The Tool Die System for Micro Forming

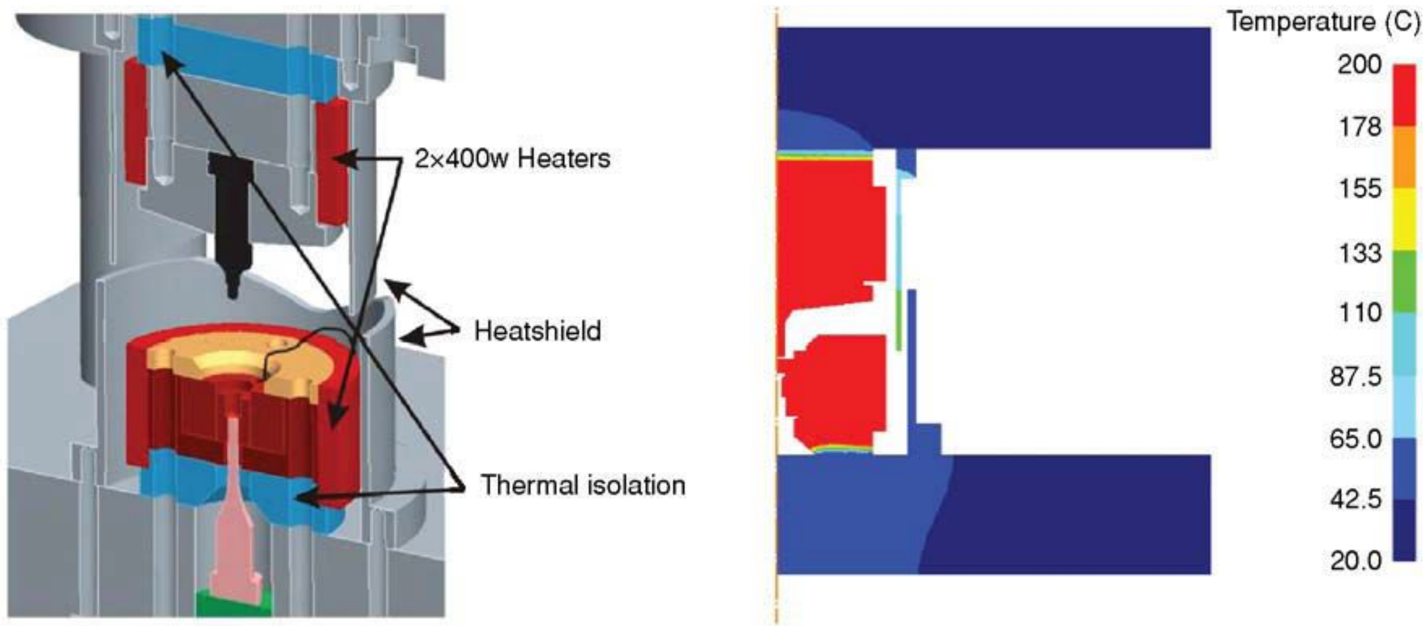


Example of a bulk forming set-up where the back-plate is used as a reference for the tooling elements



(a) (b)

Sectional view of a two stage micro-bulk forming machine



(a) (b)

A prototype tool system for warm micro-bulk forming of a dental implant in titanium

Parameters Influencing Punching/shearing process

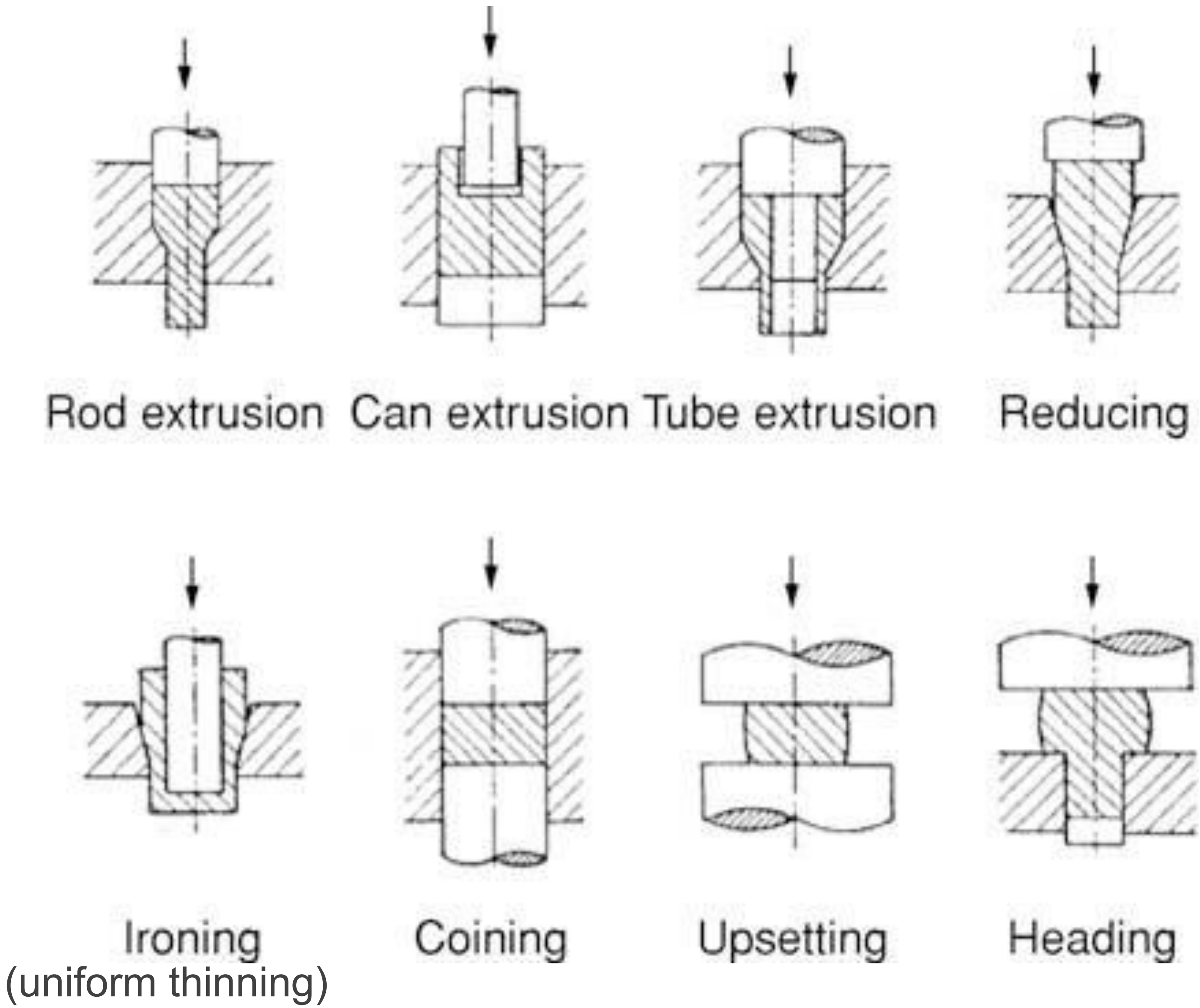
- Punch die clearance

  Conventional – 4-8% of sheet thickness (t).
  Small clearance – large cutting forces.
  large clearance – Burr formation – counter punch.

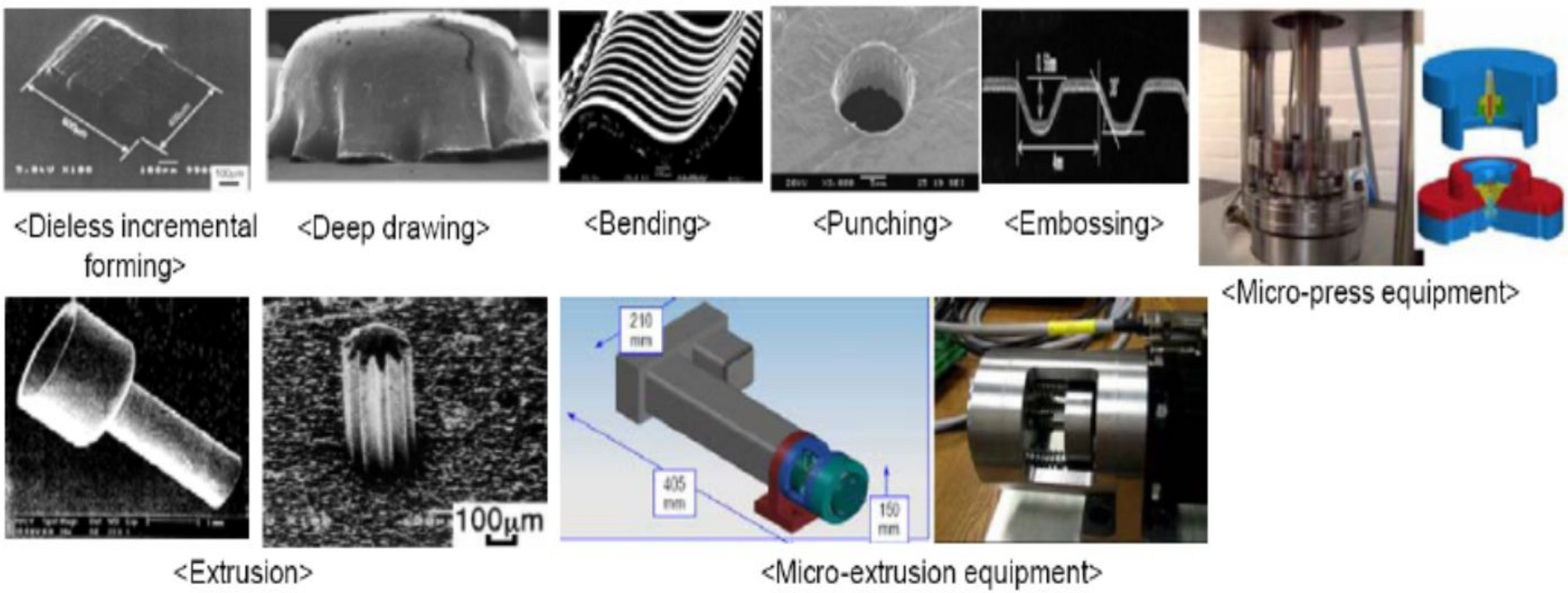
- Punch and Die dimensions
- Punch velocity
- Alignment of tools
- Strain rate

- Sheet metal materials
- Sheet thickness

Basic cold forming processes



Different operation



Cold heading and extrusion

1. Wire has to be cut first in order to produce a billet of well defined length.
2. Transfer from the cut-off station to the forming station and a precise positioning in the die is necessary.
3. Required speed and precision in combination with the low weight of the billet (a few milligrams), which makes gripping and positioning difficult, is a major limitation for miniaturization.

Example: The small part produced by a multi-stage forming operation, Shaft diameter of 0.8 mm with wall thickness of 125 µm

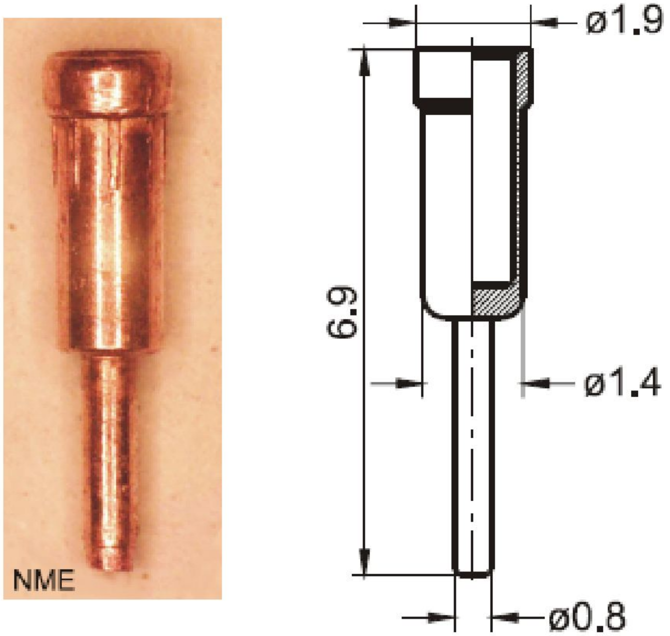


Figure 6: Extruded copper pin (NME)

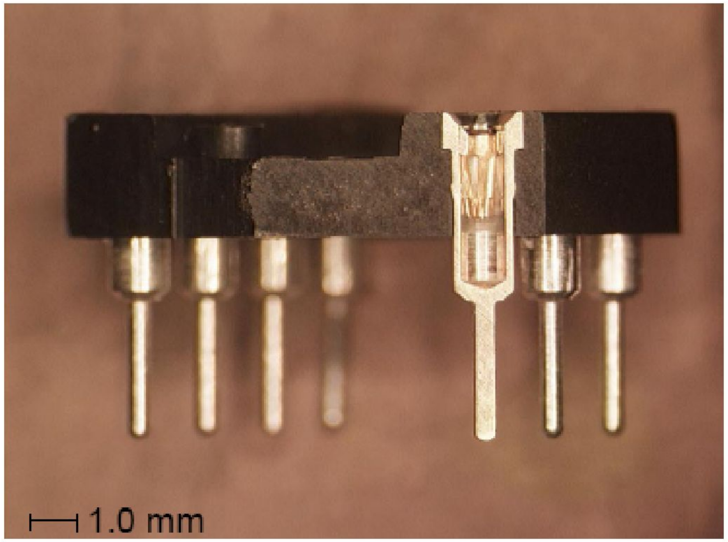
Cold headed parts with simple shapes

- One-die-two-blow machines
- Two forming operations in one die by moving the part within die to second punch or by moving punch- Problems of handling and positioning can be avoided.
- The smallest wires down to 0.3 mm

Miniature screws

Wire diameters down to 0.1 mm

: Micro screws



Pins used for IC-carriers

Cold forging

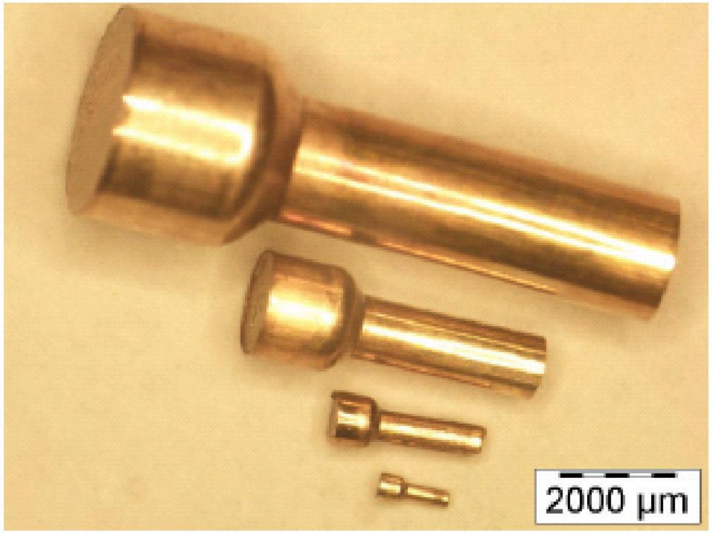


Figure 21: Geometrically similar parts, forward extruded (LFT)

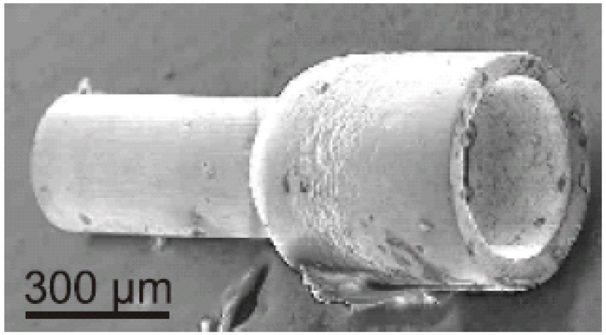


Figure 23: forward rod - backward can extrusion; initial diameter: 0.5 mm, wall thickness: 50 µm (LFT)

LFT- Long Fiber Thermoplastic Extrusion

parts for automotive applications such as

- front-ends,
- bumper beams and
- underbody shields.

Embossing/ Coining

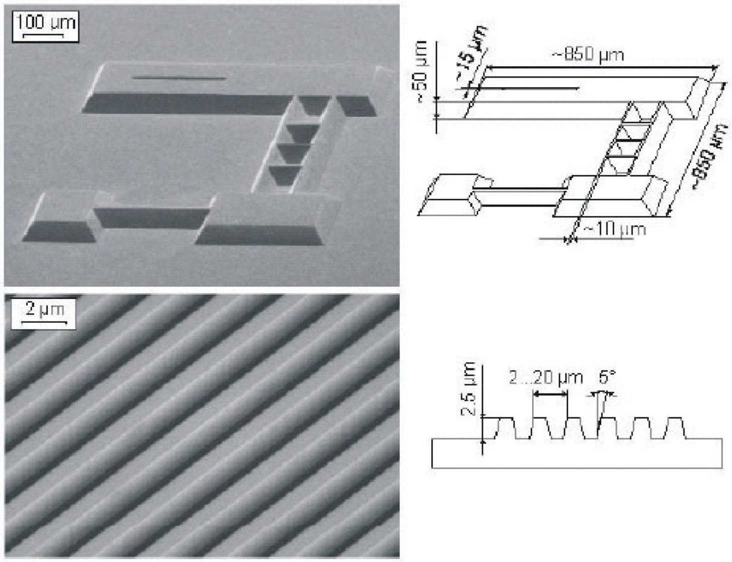


Figure 24: SEM-picture of silicon tools used for embossing (IWU)

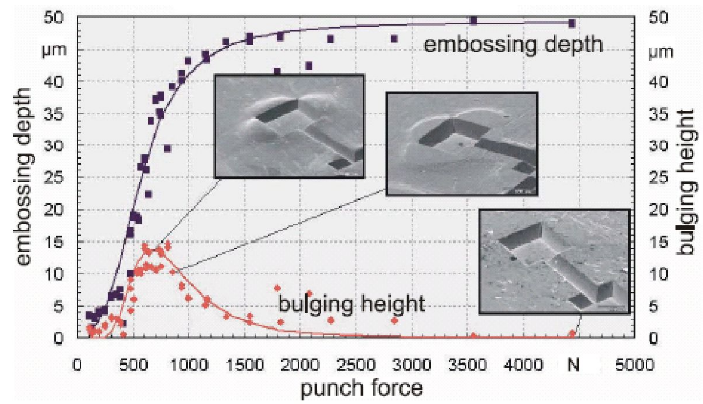


Figure 26: Relation between embossing depth, bulging height and punch force for aluminum (IWU)

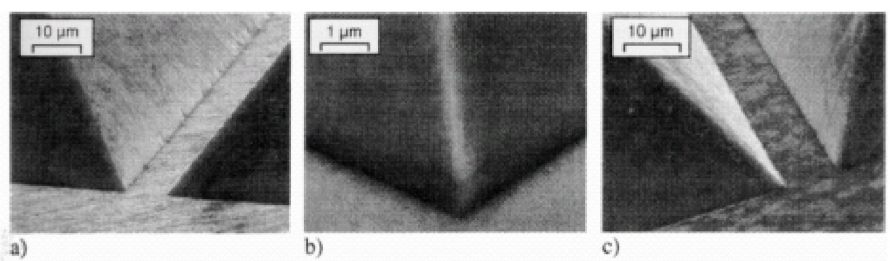


Figure 25: Detail of microgeometry after cold embossing a) aluminum, b) brass, c) stainless steel (IWU)

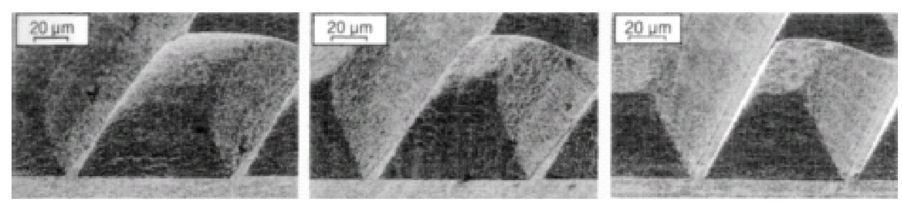
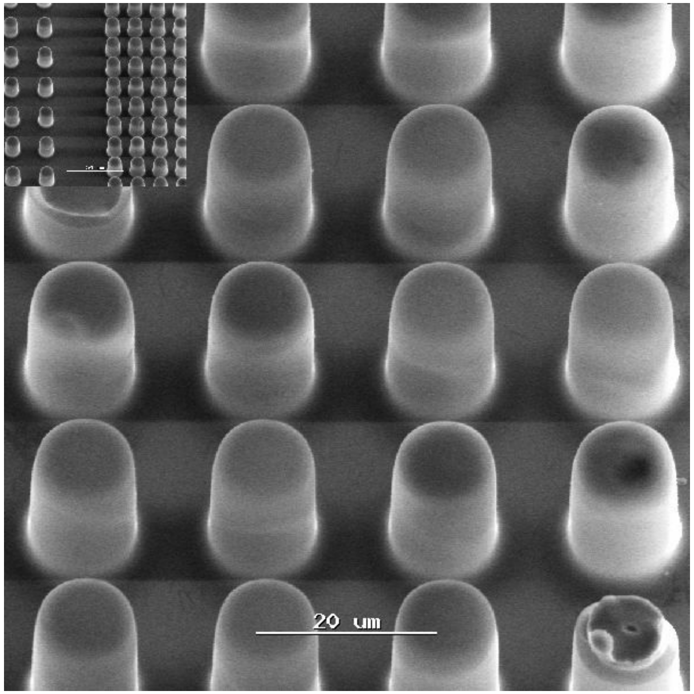
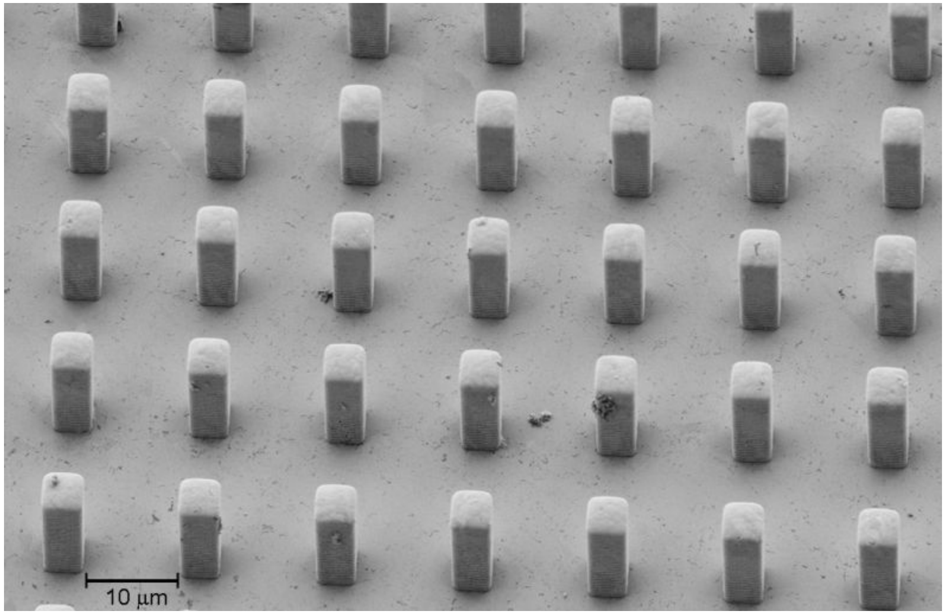


Figure 27: Detail of microgeometry in ZnAl after superplastic embossing:
25 MPa, 5 min; 25 MPa, 15 min; 37.5 MPa, 5 min (IWU)

Bulk metallic glasses



Ag microforming

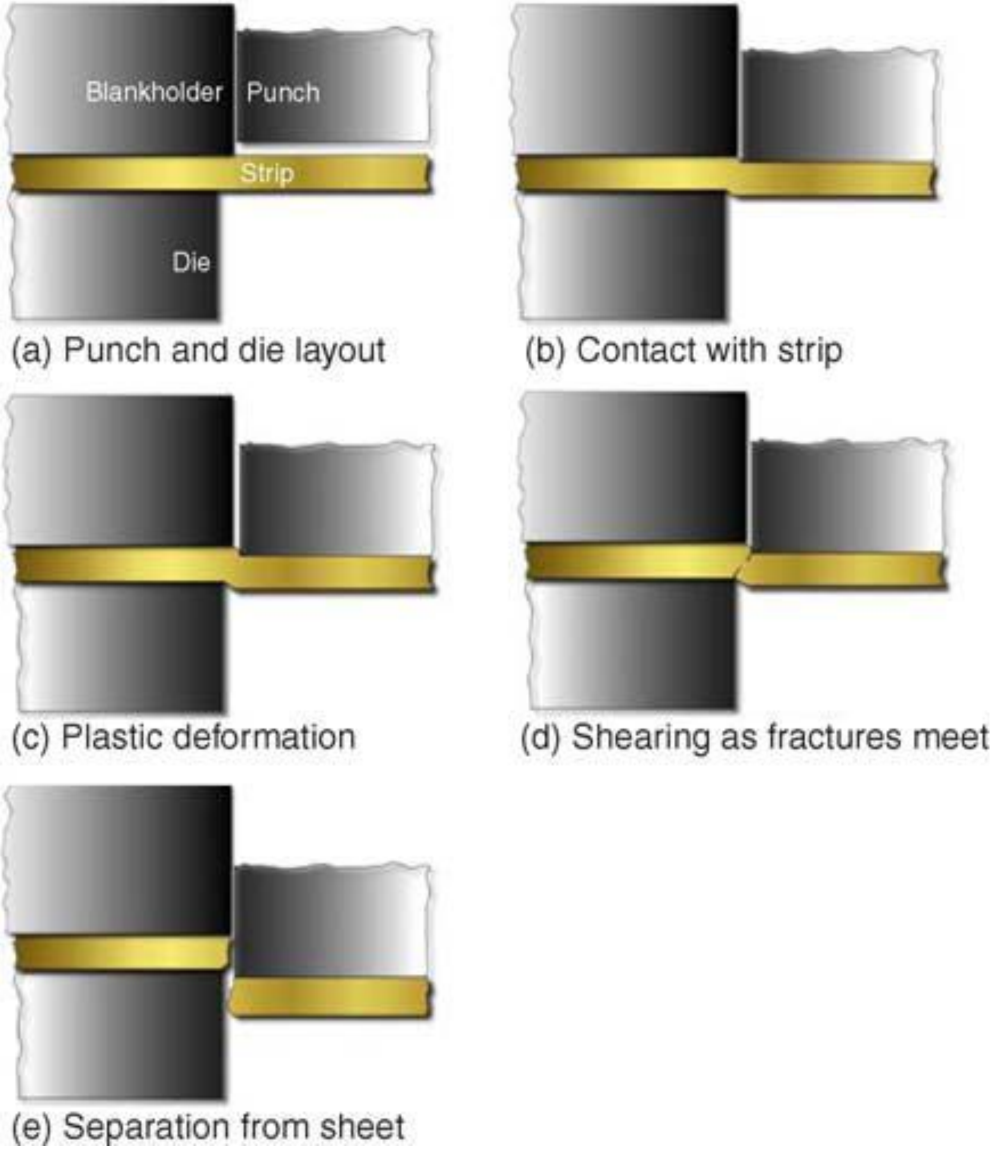


Forming of Micro-sheet metal components

APPLICATION OF MICRO FORMING OF SHEETS

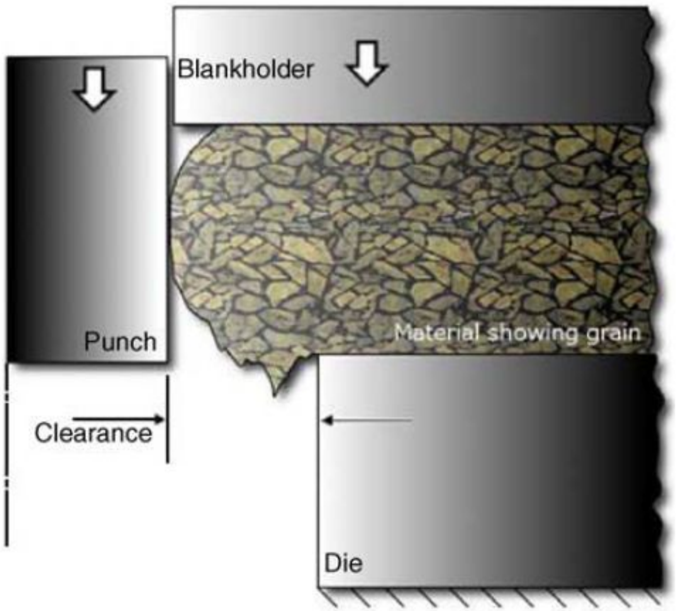
PARTS	PROCESS	MATERIAL	APPLICATION
Micro cups	Micro deep drawing	Molybdenum, Cu, Al, Steel	Electron guns, pressure Sensors
Lead frames	Micro stamping	Cu & alloys, Steel	Electronic products
Housing for micro devices	Micro stamping, Deep drawing	Stainless steel, Al, Cu	Micro mechanical, optical devices

Forming of Micro-Sheet- Metal Components



Stages of a shearing/cutting process

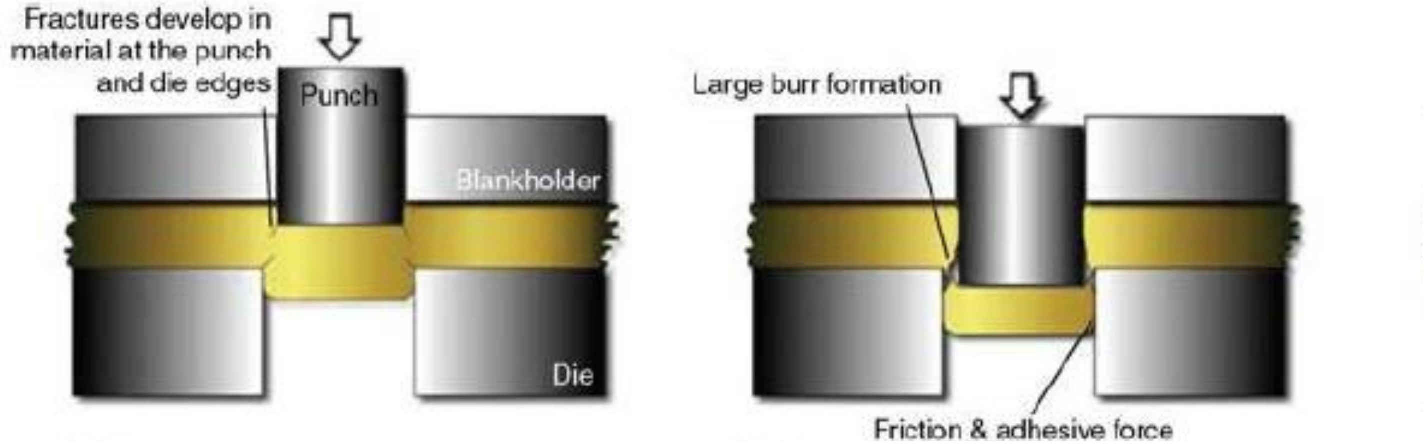
SIZE EFFECT IN SHEARING



- ❑ Edge quality is dependent on size, orientation, grain boundary properties in micro shearing
- ❑ Shearing resistance increases with scaling down
- ❑ Limited number of sliding planes

EFFECT OF CLEARANCE

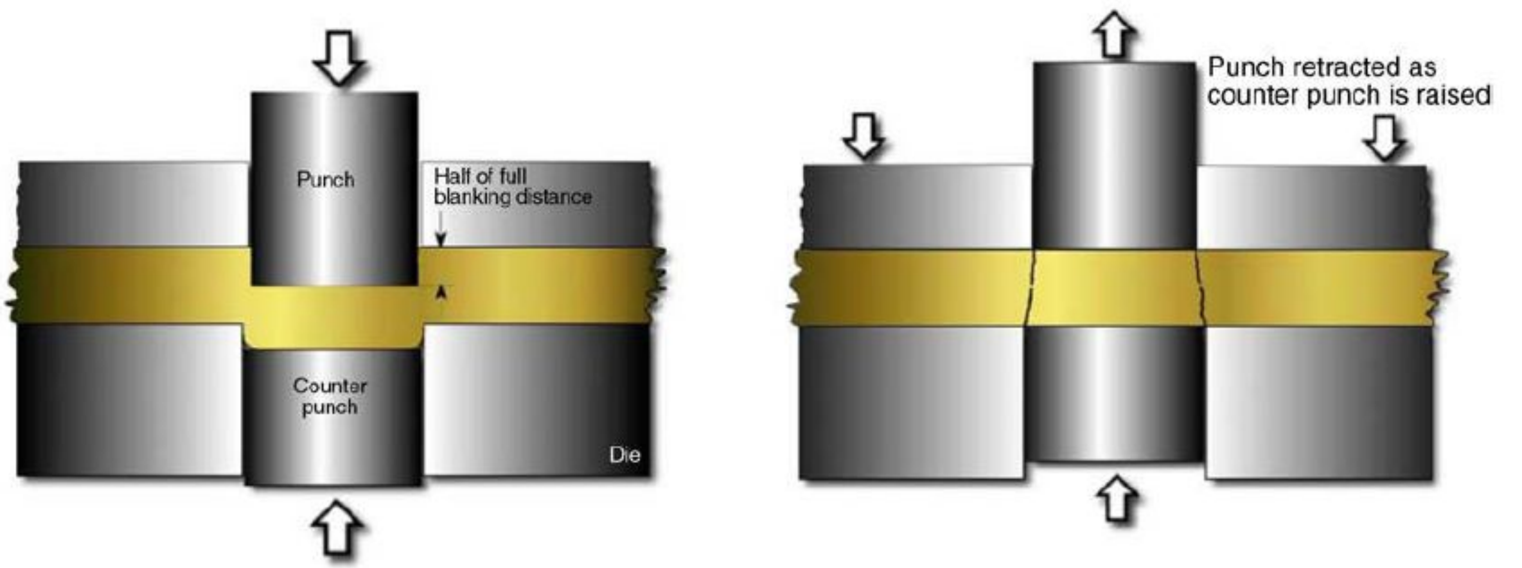
- Blanking of 20µm thick sheet strip, ideal clearance will be 1-2µm.
- This causes difficulties in tool fabrication
- Offset due to deflections can be more than 1-2µm resulting in tool damage
- Leads to employing large clearance value



POST PROCESS BURR REMOVAL

Mechanical methods

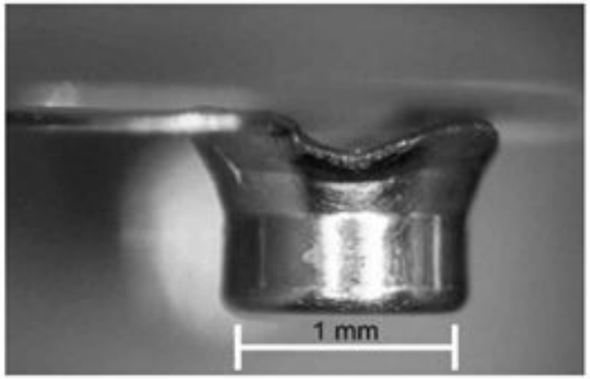
Controlling the half blanking depth is crucial



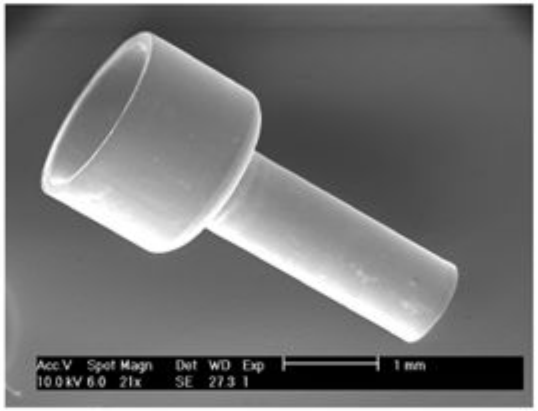
Burr free punching process

Micro Sheet Metal Working Processes

1. Bending, deep drawing and stretch forming cups for the electron gun in color TV sets

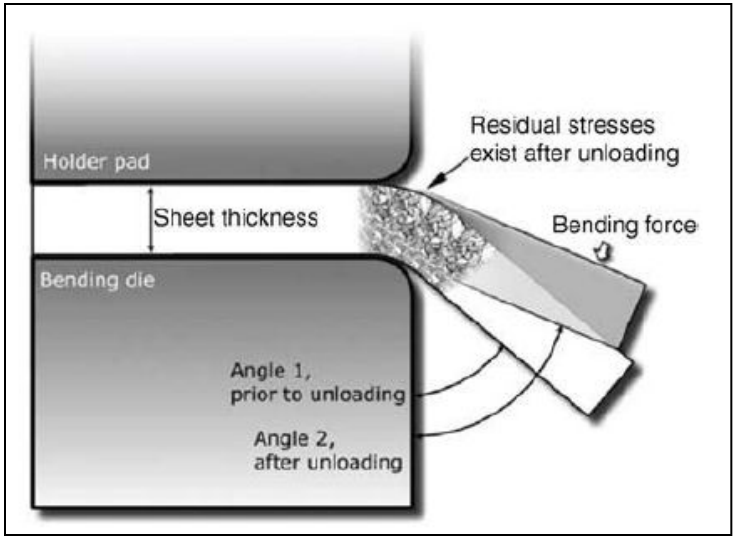


2. Shafts of small motors by progressive tool within 18 steps



Shaft of a micro motor; material: SPCE steel

MANUFACTURE OF SHEET METAL PARTS BY BENDING

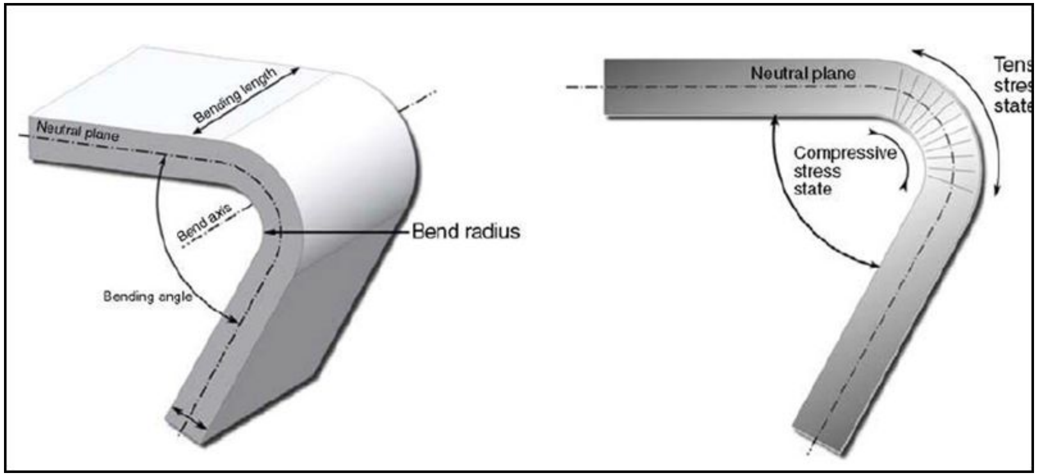


SPRING BACK WHILE BENDING

Spring Back

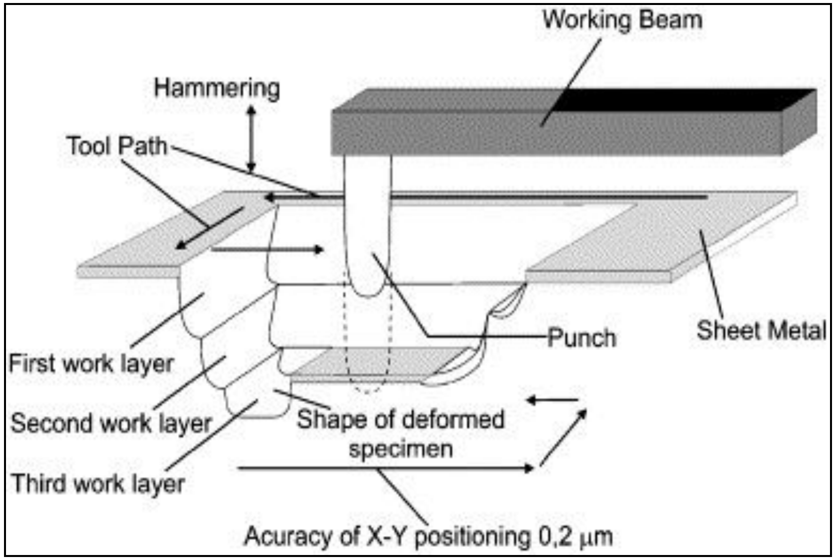
- ❑ Immediately After bending
- ❑ During secondary processing

- Avoiding Spring back
  - Re-bending,
  - Over-bending,
- Additional tools:
  - Complexity of geometry,
  - Extra tool cost
- In process measurement of spring back , adjustment of bend angle, bend speed etc



Incremental micro sheet metal forming

- Incremental micro sheet metal forming by hammering
- The metal sheet of 10 μm in thickness was hammered by a punch of 10 μm in diameter in several layers
- The sheet is guided under the punch by a 3D-CNC positioning machine with servo motors in an accuracy of 0.2 μm.
- The working process was online observed in a SEM field



Wire bending for filaments and springs in medical and electronic industry

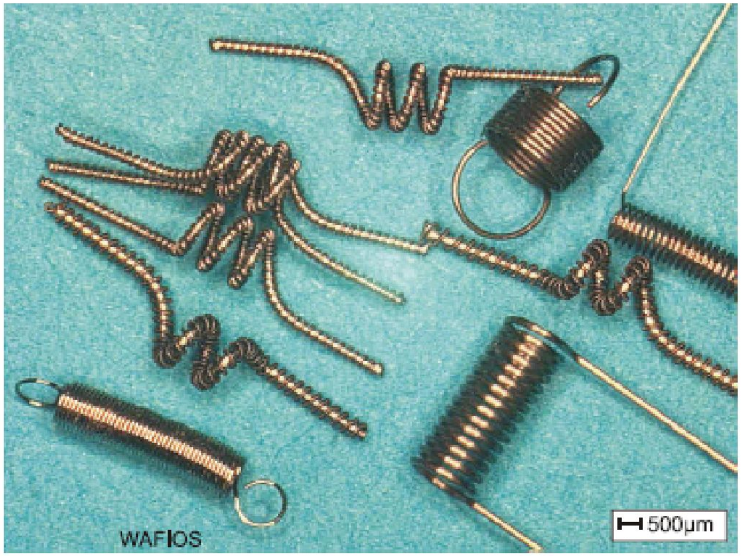


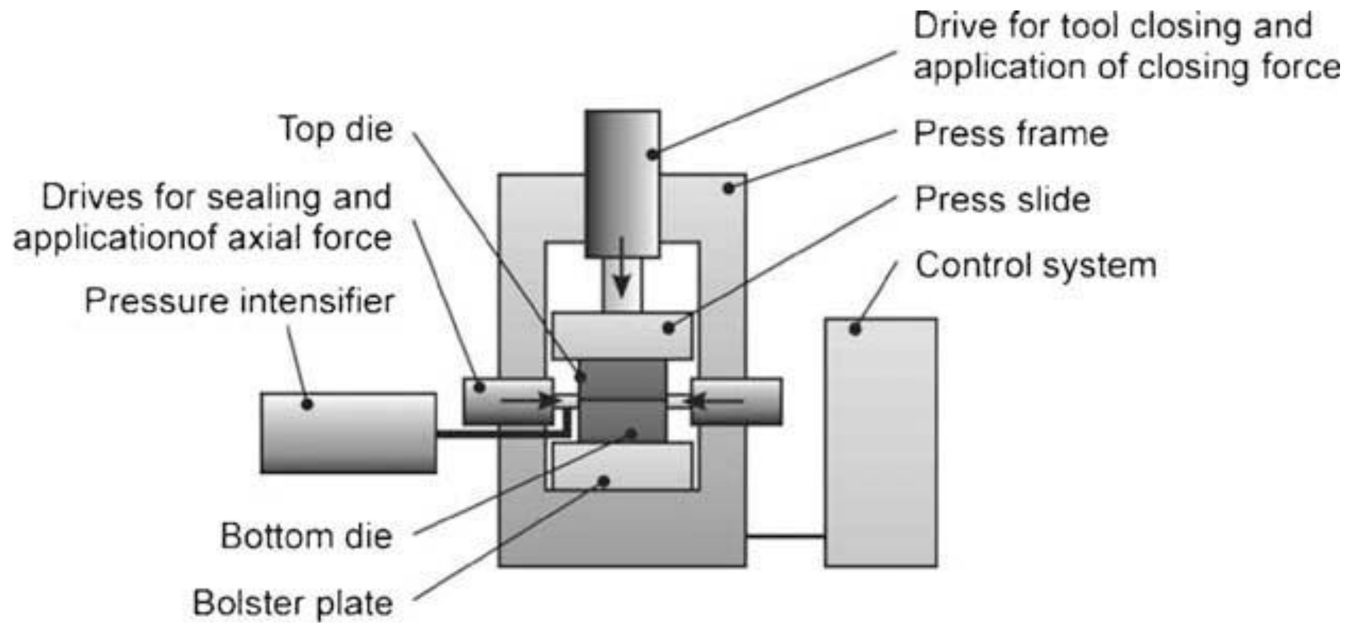
Figure 5: Micro springs and filaments (Wafios)

1. Wire is fed from a coil into the machine and led into a die
2. When leaving the die with a controlled speed, the wire is bent with the aid of several shaping tools.
3. At the end of the forming process the finished part is cut off from the wire
4. minimum wire diameter of 100 µm and produce up to 450 parts per minute
5. Special purpose with wire diameters down to 60 µm (spirals for endoscopy)
6. miniaturization limited by the accuracy in shape and movement or control of the tools

Micro-Hydroforming

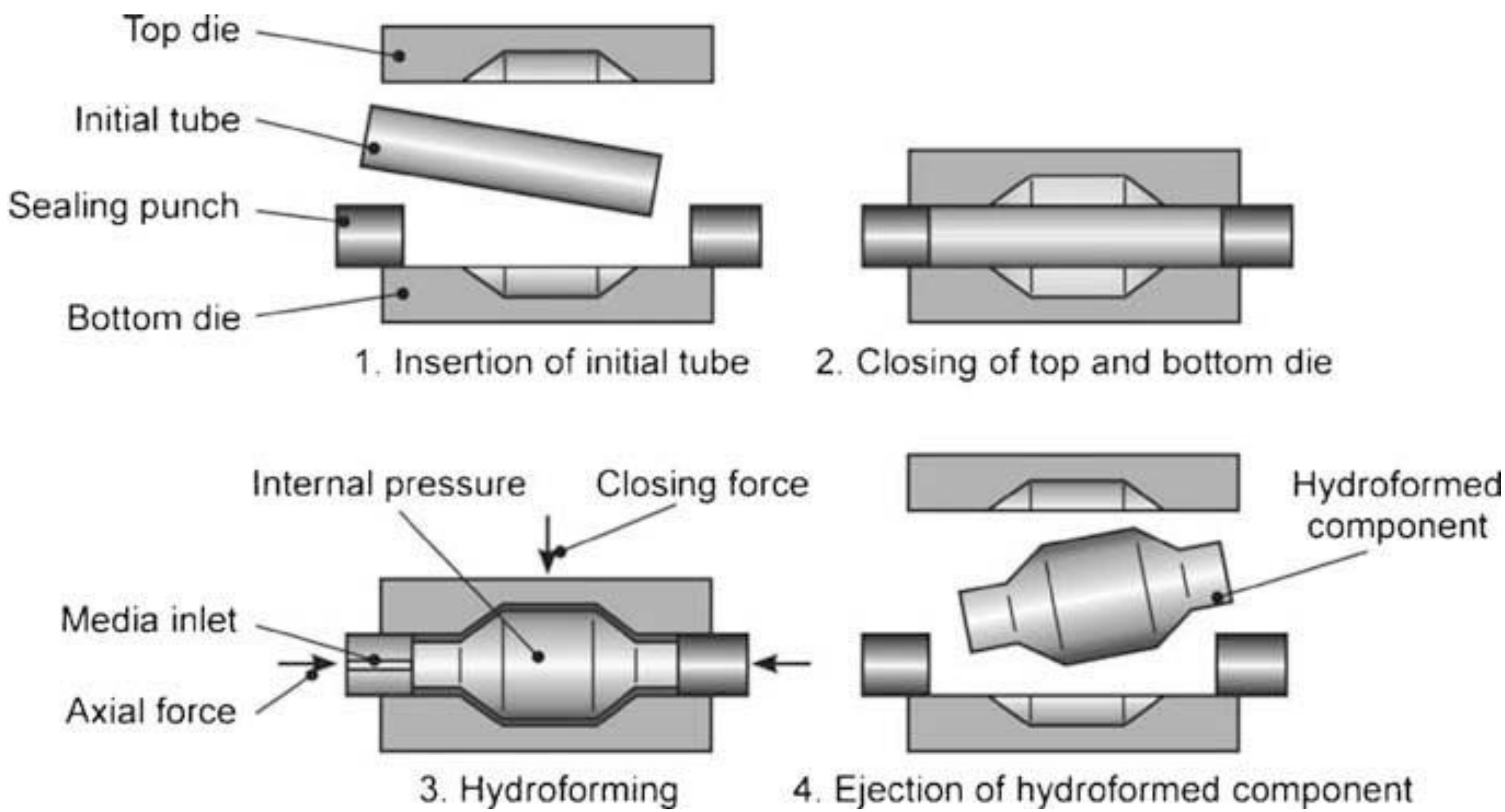
Micro-Hydroforming

- Hydro forming is a metal forming technology based on the application of pressurized liquid media to generate defined workpiece shapes from tubular materials or sheet metals.

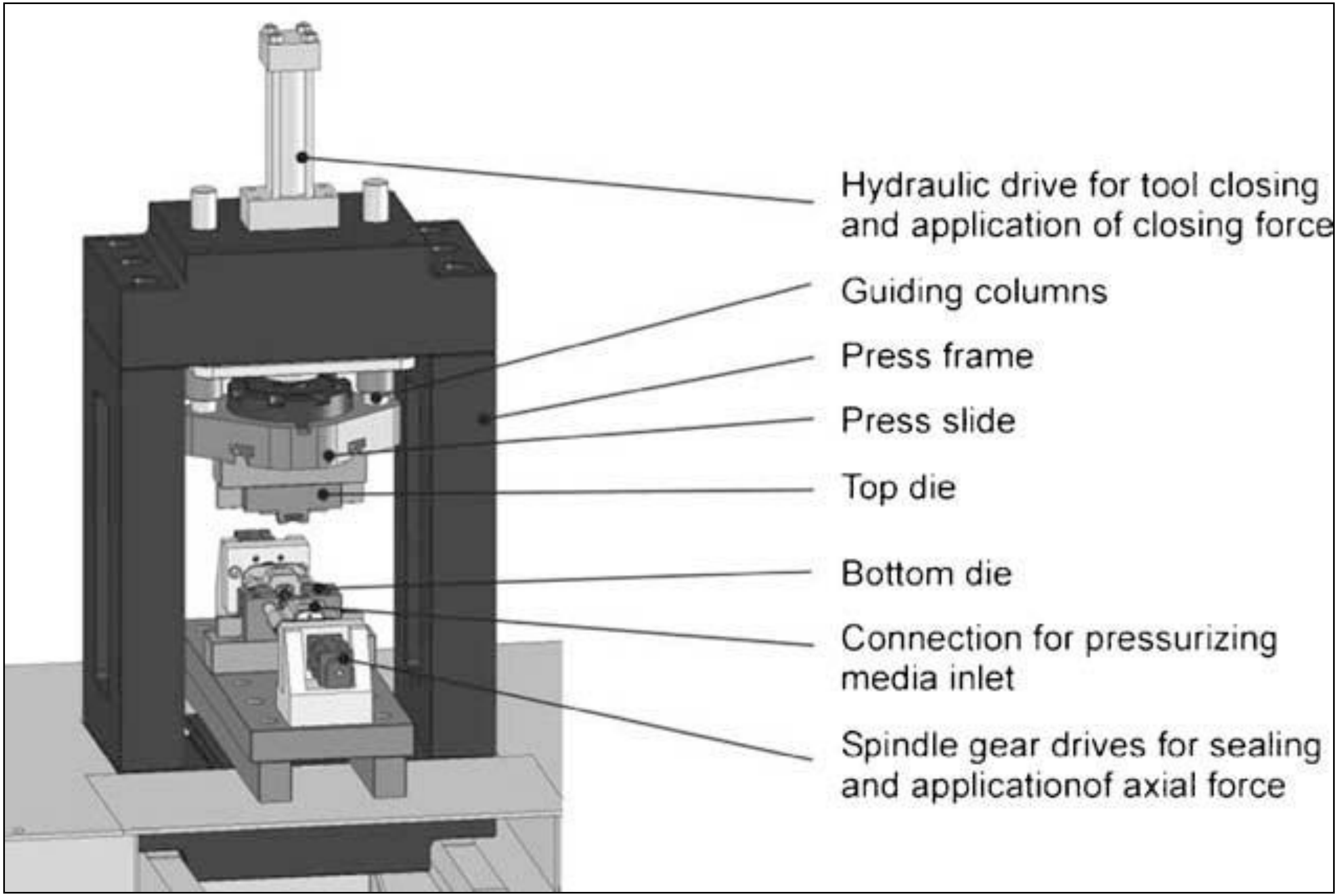


Elements and functions of the hydroforming machines

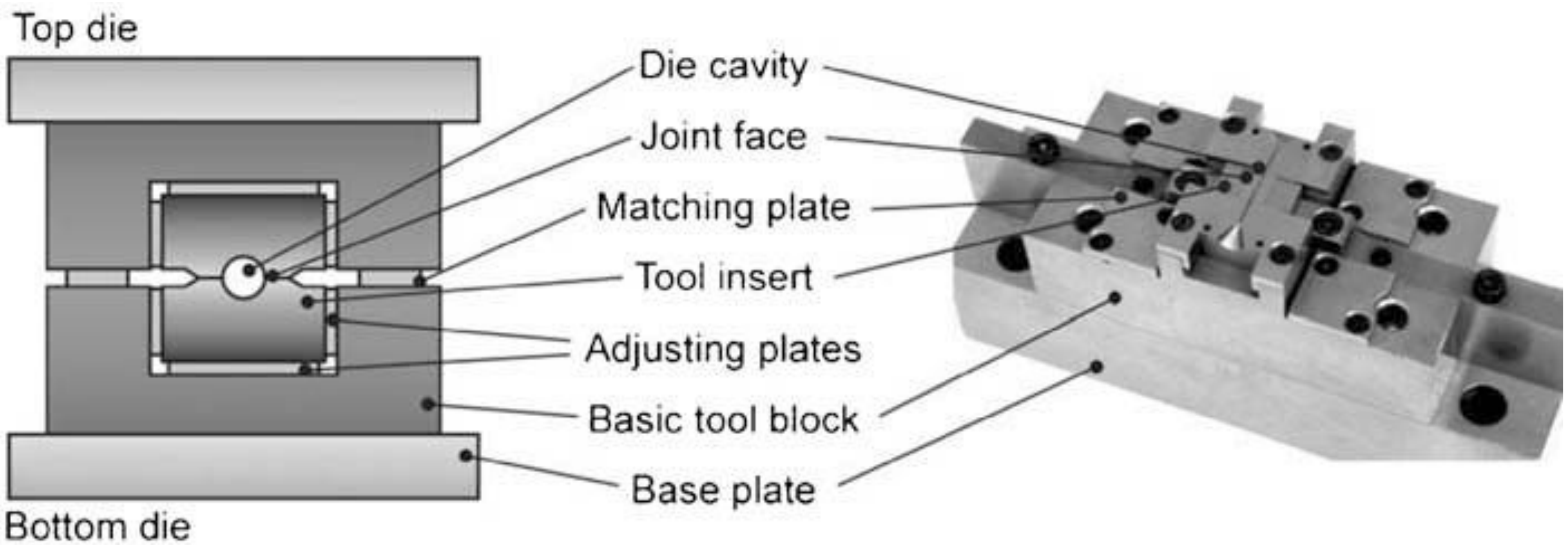
Hydroforming principle



Micro-hydroforming prototype machine

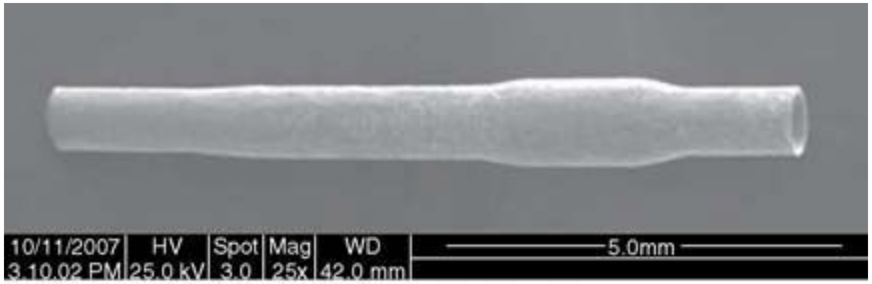


General design of micro-hydroforming tools



Hydroforming tool cross section

Bottom die of micro-hydroforming tool



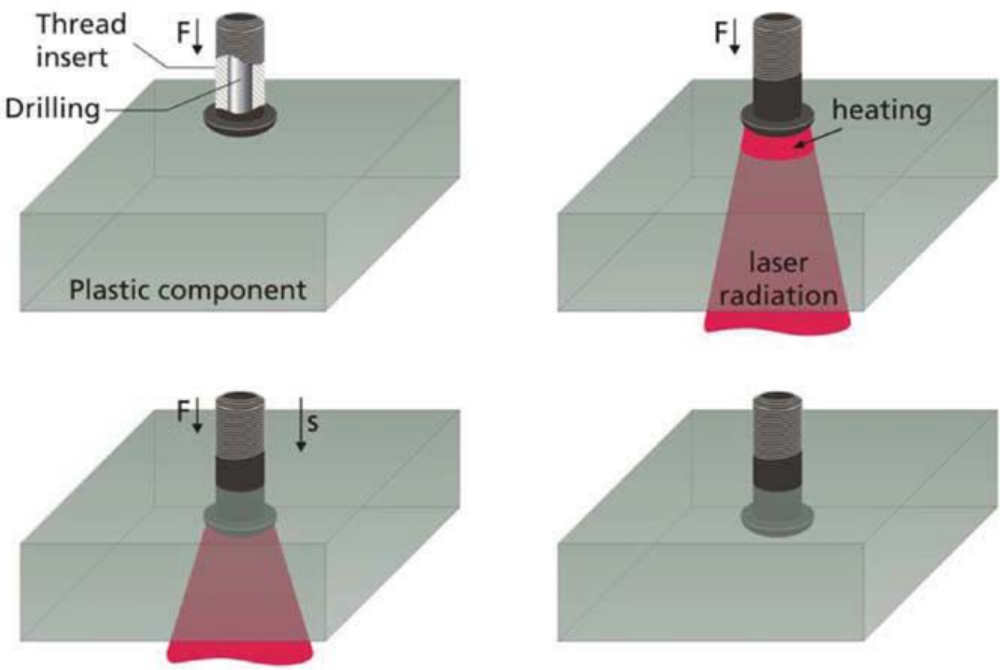
Micro-hydroformed component

Laser Assisted Micro forming

Laser-Assisted Micro-Forming

Fixing a metal part to Plastic component:

1. Positioning and applying pressure;
2. Heating the metal part through the plastic component with laser radiation;
3. Penetration into plastic component after exceeding glass transition temperature;
4. Cooling down and the creation of positive locking.



Process sequence

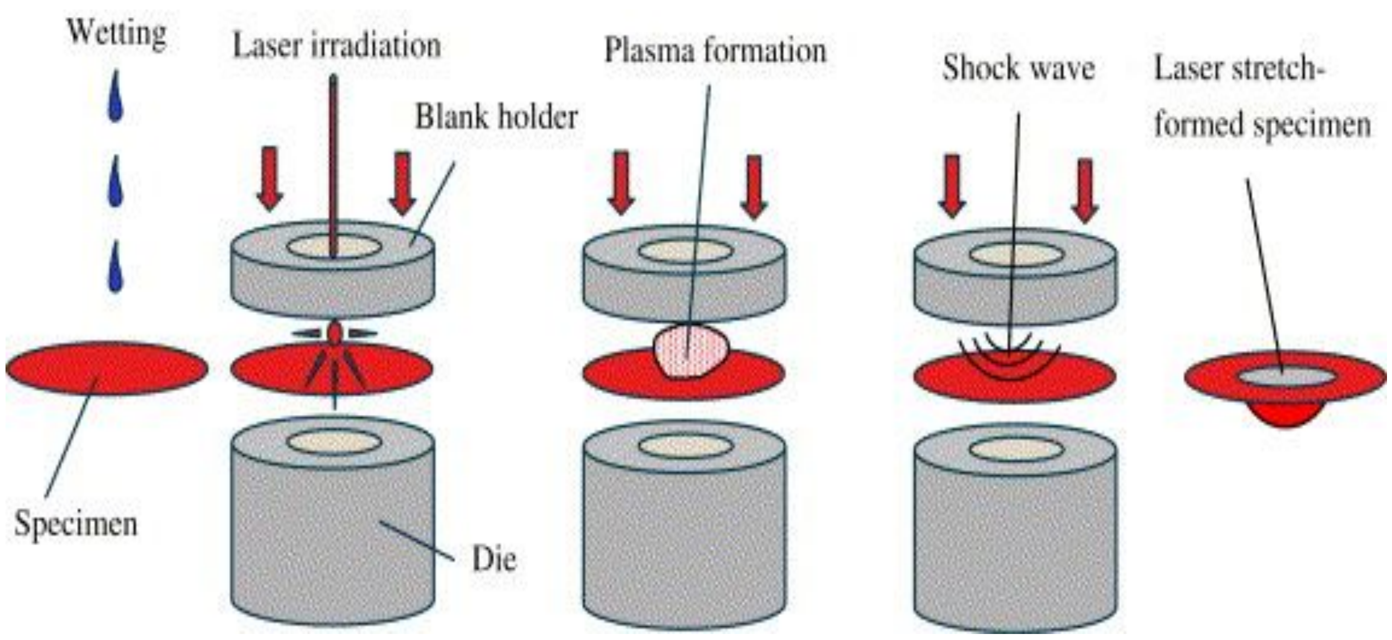
LASER SHOCK MICROFORMING

Laser Shock Microforming (LSμF) is based on the application of a high intensity pulsed laser beam (I > 109 W/cm2; τ < 50 ns) on a metallic target forcing a sudden vaporization of its surface into a high temperature and density plasma that immediately develops inducing a shock wave propagating into the material.

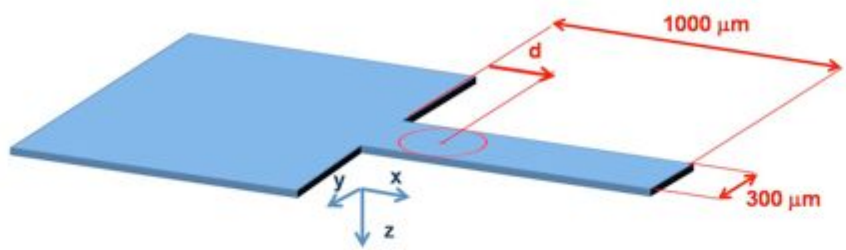
- When the laser is switched off, the plasma continues to maintain a pressure which decreases during its expansion.

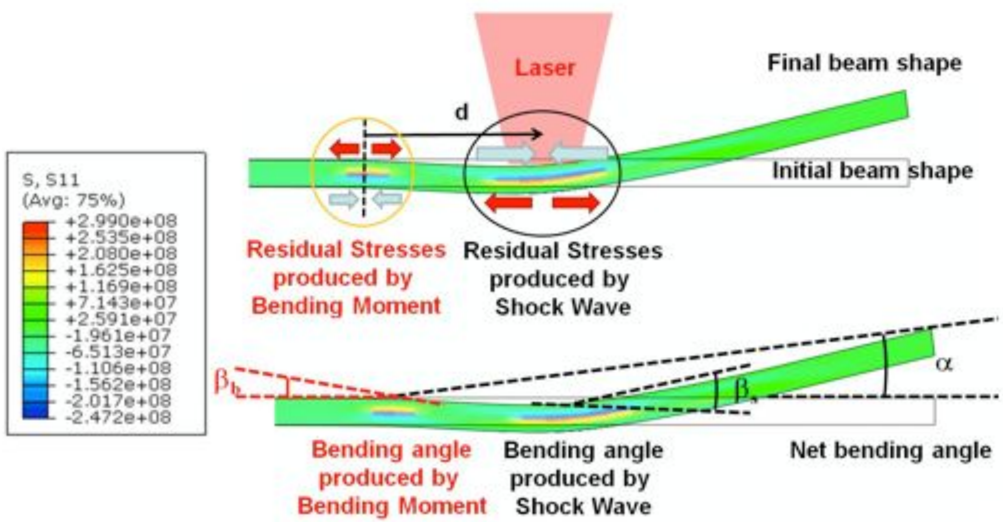
In Laser Shock processes the material is stressed and deformed in a dynamic way, with strain rates exceeding (~104 s-1). The actual material yield strength is taken according to Von Mises' criterion.

Schematic process of non-thermal laser stretch-forming



LASER SHOCK MICROFORMING





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3. F. Vollertsen , H. Schulze Niehoff, H. Schulze Niehoff, Z. Hu, H. Schulze Niehoff, Z. Hu, State of the art in micro forming, International Journal of Machine Tools and Manufacture, H. Schulze Niehoff, Z. Hu, State of the art in micro forming, International Journal of Machine Tools and Manufacture, Volume 46, Issue 11, September 2006, Pages 1172–1179

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Microforming

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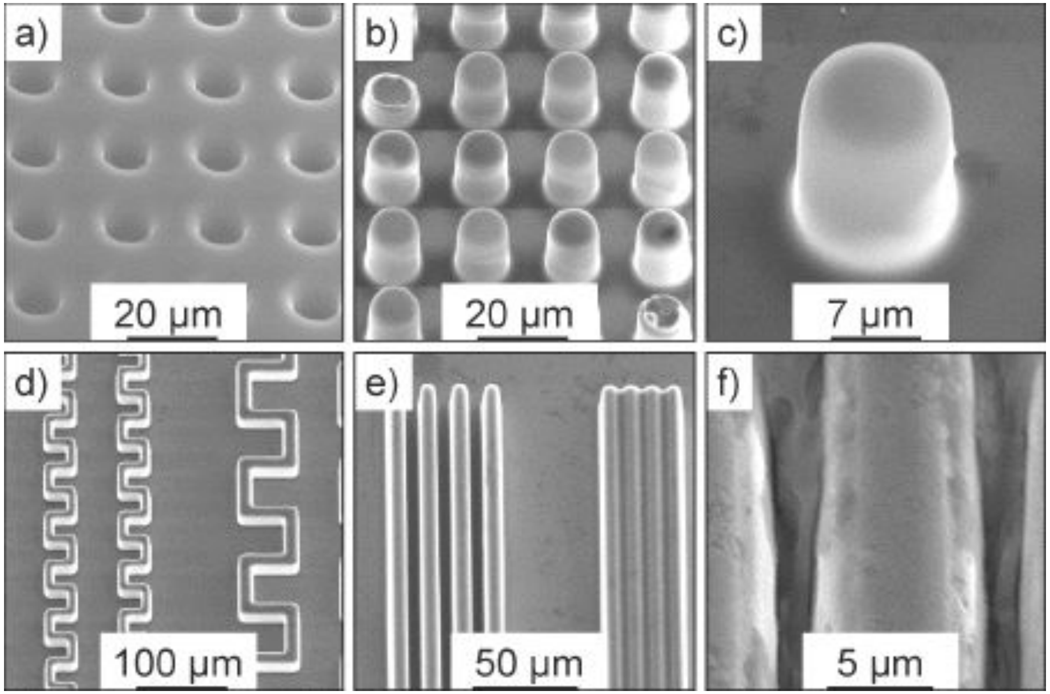
Details of test structures replicated into bulk metallic glass



a) silicon mold and **b)** its replication in bulk metallic glass with **c)** a detail. Pins of 10 μm in diameter and 20 μm height are completely replicated. A protective coating of 1 μm SiO_2 is still present on the metallic glass after removal of the Si wafer by etching. **d)**and **e)** show rims with **f)** a detail of 1 μm spaced rims. The mold did not melt and connect the rims, but the silicon mold between the rims is still present due to a decreased etch rate in narrow channels.

General Considerations in Micro Manufacturing

- Whether the maximum stamping force requirements, machine static/dynamic characterisation can be met with the available machines.
- Whether the machine strokes and manufacturing precision requirements can be met with available machines and tools.
- Whether production rates achievable are acceptable.
- Whether the raw materials obtainable meet the requirements in terms of mechanical properties, grain sizes and dimensional tolerances for production.
- Whether the tool design/manufacturing capabilities meet the requirements.
- Whether the punch and die clearance recommended is achievable.
- Whether a burr removal process is required.
- What extra care for handling fragile thin strips and structural parts is required.
- Whether a push-pull feeder set up is required.
- What extra measures for reducing springback is required.
- How the process monitoring, tool wear condition will be monitor.

Microforming

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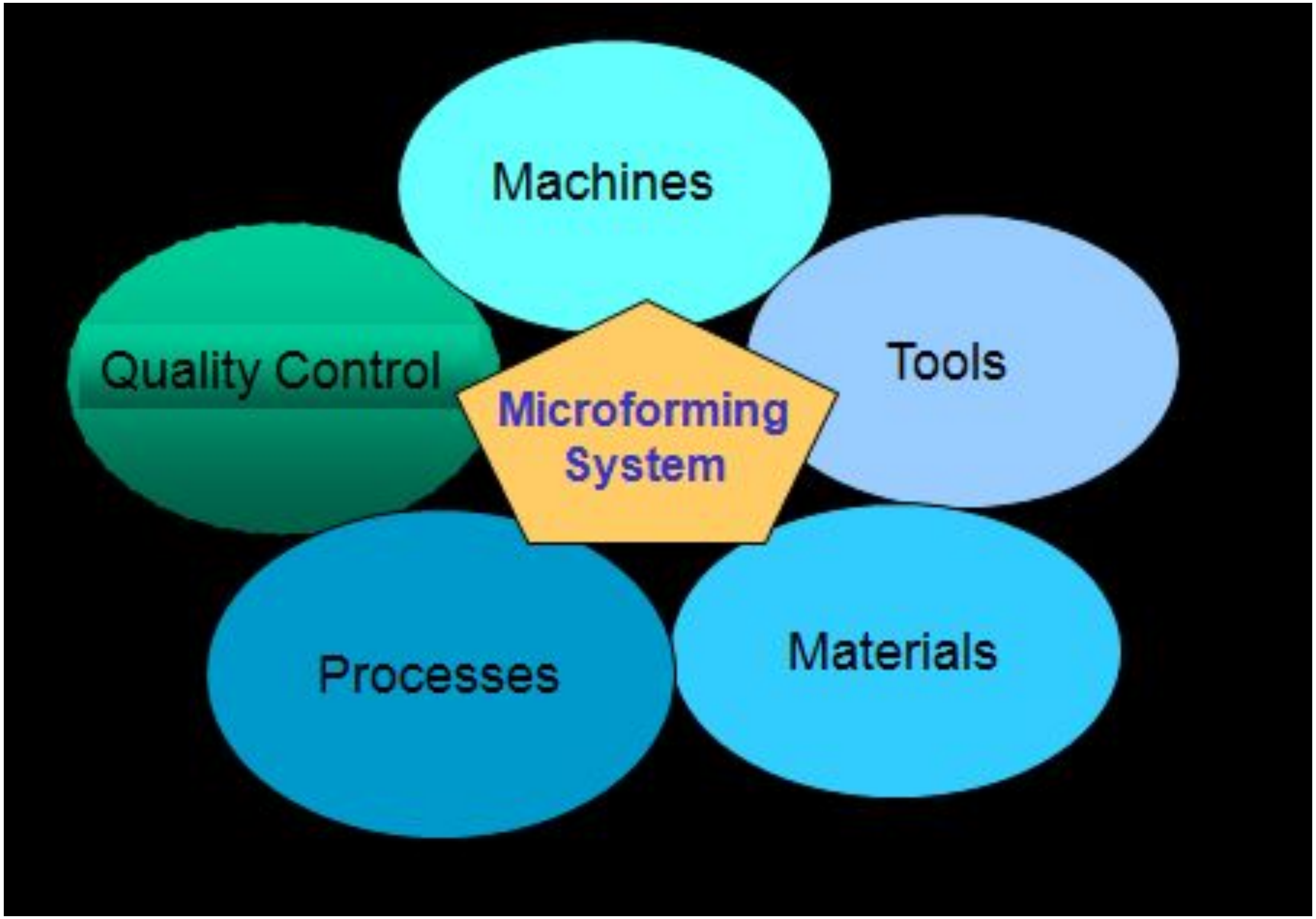
(MEMS). These terms as well as the examples mentioned above imply already what characterizes the challenges for current and future developments: the distinct interdisciplinary approach bringing together the know-how of electronics and mechanics, or more detailed, of physics, chemistry, material science, manufacturing technology and many others. As this represents one of the characteristics of MST another item underlining its significance may be given by looking at the market. The world-wide turnover of MEMSs grew from 14.4 bn € in 1996 to more than 33 bn € estimated for 2001 [3]. Despite of this, there are only a few typical products known, justifying this development by an extremely successful dissemination, as e.g. inkjet printheads and airbag systems. The real breakthrough of MST is still missing [4,5]. One of the reasons seems to be the fact that technologies, well known and established in the macroworld, cannot be simply scaled down to be applied on the microscale. Alternative manufacturing methods suited to fit the demand for economical production have to be developed. Public research programs like "Research and Development of Micromachine Technology" in Japan or "Micro Mechanical Production Technology" in Germany deal with this challenge, [4] and many technologies for micro part manufacturing, handling and assembly are being developed [6,7].

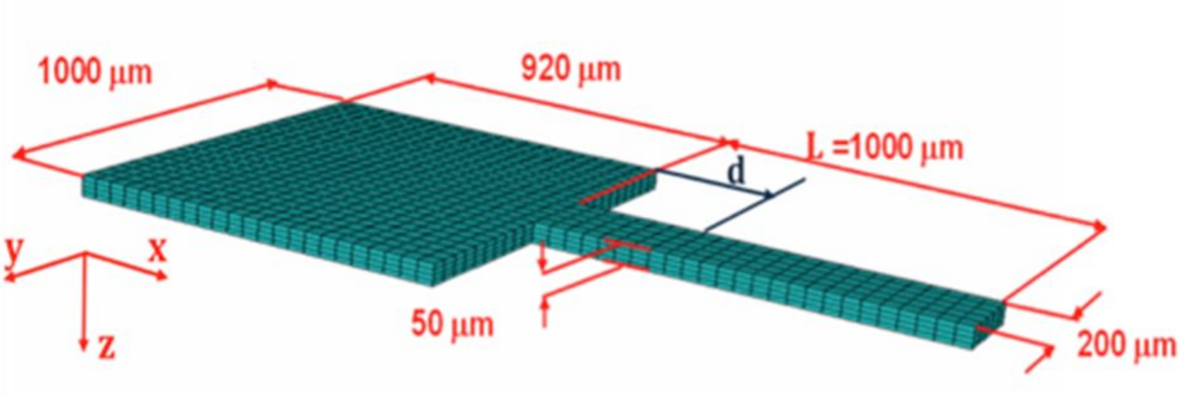
These are facets of a technology's development that need to be monitored closely. CIRP is doing this

corresponding to the definition of 'micro' as discussed in [6].

Figure 1: Miniaturization: Hard disc drive, capacity one Gigabyte (IBM)

Micro-Forming Systems

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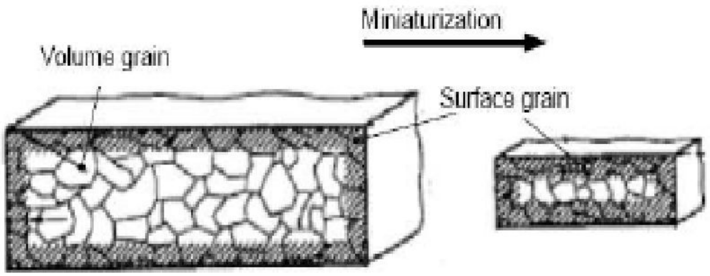
Thank You

SIZE EFFECT



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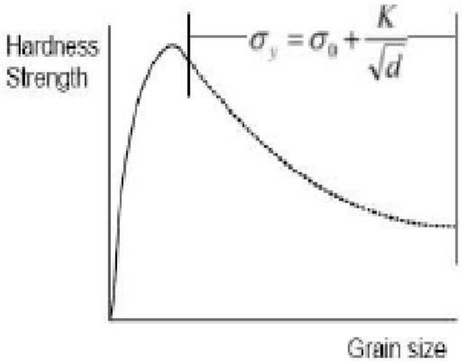

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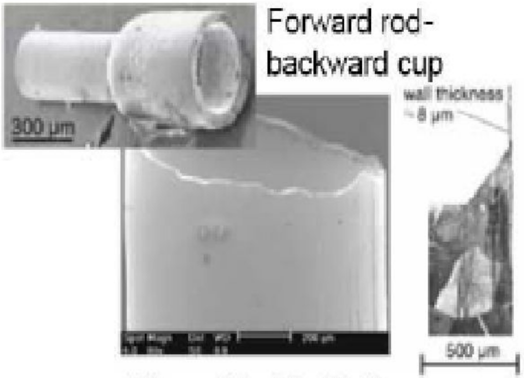

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