Micro forming

- Micro forming
  - Micro injection molding
  - Micro metal forming


Micro Forming Parts

Metal Forming System

Micro Metal Forming System

Fig. 2. Problems in the microworld (LFT).

Fig. 4. Relation of surface grains to volume grains [13].

Fig. 5. Microformability of polycrystalline and amorphous material [15].
Fig. 7. Tool concept for laser supported part heating in micro deep drawing.

Fig. 8. Incremental sheet metal forming by hammering [22].
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Fig. 8. Effect of miniaturization on areas with open and closed lubricant pockets (LFT).

Fig. 9. Forward rod—backward can extrusion; initial diameter is 0.5 mm (LFT).
Fig. 11. Backward extruded part, thickness of the wall 8 μm, SEM picture (left) and cross-sectional micrograph (LPT).

Fig. 12. Irregular hardness distribution of a coarse grained extruded specimen, initial diameter of 63 mm (LPT).
Fig. 13. Bending forces and yield strength in bending tests. Effect of miniaturization and grain size (LFT, mate).

Fig. 14. Strain distribution of fine grained material (LFT).
Fig. 15. Inhomogeneous strain distribution of coarse grained material (LFT).

Fig. 17. Warm forging: flow stress and scatter decreasing with temperature (LFT).
Review of state of the art in micro forming


Sources of size-effects

- Physical
  - Pure volume size effects
  - Surface to volume size effect
  - Forces relation size effect
- Structural sources
  - Grain size to thickness size effect
  - Surface structure scalability size effect
Surface to volume size effect

- Surface/Volume (S/V) ratio
  - When the part size decreases, the ratio S/V increases, which makes the surface effects more important.
- Affect heating/cooling
- Affect the contact interface
  - Friction
  - Heat transfer

Forces relation size effect

- Vander-Waals-force
- Surface tension
- Gravitation
  - These forces are very small and can be neglected in conventional forming of macro parts. But for the micro forming these forces must be taken into account, because they are relatively big regarding to the process forces.
Grain size to thickness size effect

- The grain size of metallic materials is dependent on the material properties and determined by the casting condition, the thermal, mechanical and thermo-mechanical treatments.
- It is impossible to generate each material with each grain size, thus the grain size cannot be scaled down like the part dimension, for example like the thickness.

Surface structure scalability size effect (I)

- Like the grain size of the material the surface structure is the result of the history of the part. It is influenced by cutting processes and surface roughening, flattering or intended structuring during forming processes.
- The result of these treatments is also influenced by the grain size, as it has an influence on the elementary processes like grain tilting in forming or elastic springback in cutting operations.
- In principle, the surface roughness is independent on the part size.
Surface structure scalability size effect (II)

- It is often not possible to reduce the surface roughness like the part dimension, due to that the surface structure scalability (SSS) can be the source of size effects.
- The micro contact remains unchanged, while the macro contact is changed due to miniaturisation.
- Especially in lubrication this leads to a size dependent friction behaviour.

Microformability of polycrystalline and amorphous material

- Grain size $D_g = \text{Width of V-groove } W_v$
- Polycrystalline material
- Grain size $D_g = \text{Width of V-groove } W_v$
- Amorphous material
Researches show that there is a transition from the polycrystalline to single crystal behaviour, if the normalized thickness of the part, i.e. the fraction of part diameter and grain size, falls below a certain value (part diameter/grain size $\sim 10$), see Fig. 15.

Above that value constant strength is detected, if the grain size is held constant and the diameter of the samples is varied, as the sample size decreases to dimensions comparable to 10 times the grain size, the region with size effects is entered.

The typical behaviour of a polycrystal, which is determined by the interaction of dislocations with grain boundaries and described by the Hall–Petch equation, transforms to the behaviour of a single crystal, as the restraints by the grain boundaries diminish.
Mechanical properties: Tensile test

- wrinkling and failure

![Fig. 1. (a) Wrinkling and failure at conventional tension test of thin sheet (thickness of 0.1 mm). (b) A schematic diagram of the inserting set without driving device [5].](image)

Tensile test: Specimen with laser grid

- Local deformation

![Fig. 2. Laser grid on a tensile specimen [5]: (a) Grid on the surface of the specimen; (b) fracture in the middle of the specimen.](image)
Flow stress: Scatter of process variables

Fig. 3. Flow stress and coefficient of variation of the flow stress at different temperatures (upsetting test) [6].

Tensile tests of aluminum sheet of constant grain size and varying overall thickness.

Calculated flow stress

- For a tension sample that is $T$ thick and $\beta T$ wide, the number of surface grains, $N_s$, may be expressed as a fraction of the total grains $N_g$ in the gage section ($d$: grain size):

$$N_s = \frac{2(\beta + 1)T d}{\beta T} N_g$$

Also,

$$\sigma_y = \frac{N_s \sigma_{ys} + N_i \sigma_{yi}}{N_g} = \frac{2(\beta + 1)}{\beta} \frac{d}{T} (\sigma_{ys} - \sigma_{yi}) + \sigma_{yi}$$

where $\sigma_{ys}$ is the grain-size independent strength of surface grains and $\sigma_{yi}$ is the Hall-Petch strength of interior grains.

(WETC report, Oct. 2005)

Calculated flow stress compared to experimental values

- Calculated flow stress compared to experimental values for a strain equal to 0.4, based on a rule of mixtures between surface and interior grains.

(WETC report, Oct. 2005)
Geometry measurement

- The measurement of the geometry is very important for the micro forming.
- It is difficult to keep the same manufacturing accuracy class for both big and small dimension.
- For instance 0.1% for 100mm means 0.1 mm, but for 1mm it means 1 μm.
- Optical measuring instruments

Micro deep drawing

- The relative punch diameter (punch diameter related to the sheet thickness) has a significant influence on the limit draw ratio (LDR): In the range of 10–100 for the relative punch diameter, the LDR decreases (2.2–2.0) with increasing relative punch diameter.
- For a relative punch diameter of 10, bending is the dominant forming mechanism since the effect of blank holder pressure on drawability has been found to be minimal.
Laser supported part heating in micro deep drawing

Fig. 4. Tool-concept for laser supported part heating in micro deep drawing [9].

Main parameters affecting micro deep drawing

- There are several parameters, which affect the process deep drawing.
- The most important one is the friction at the flange and at the radius of the die.
- This friction is also effected by size-effects when transferring the forming technology from macro to micro forming. Therefore a
Friction coefficients

- The friction coefficients at the flange ($\mu_1$) and at the die radius ($\mu_2$) were calculated from the punch force and the punch stroke of the deep drawing process.

Fig. 6. Calculated friction coefficients of micro strip drawing [12].

Incremental micro sheet metal forming

Fig. 7. Incremental sheet metal forming by hammering [13].
Laser micro forming

- Micro bending
  - The most important factors are
    - the energy density,
    - the number of laser pulses,
    - the material thickness, and
    - the material properties.

![Copper foils (left) and copper wire (right), bent by pulsed laser radiation, foil thickness and diameter of the wire: 50 mm [16].](image)

Cold headed parts

- Cold headed parts can be formed in same dimensions and with special machine equipment even down to wires of 0.3mm in diameter
Metal flow in DCE test depending on friction

- double cup extrusion test (DCE)
- diameters of 4–0.5 mm.

Fig. 5. DCE test: (a) dependence of cup height on friction; (b)–(d) FEM calculation, development of the cups.

DSC: Double Cup Extrusion
Fig. 6. Increase of friction indicated by the cup height ratio of a DCE test depending on punch travel.

Open and Close Lubricant Pockets
Open and Close Lubricant Pockets

Fig. 8. Effect of miniaturization on areas with open and closed lubricant pockets (LFT).

Micro Metalforming with Silicon Dies

Fabrication of diamond dies for microforming


Fig. 6. SEM micrographs of the fabricated diamond dies: (a) pyramids; (b) square poles and crossed wall; (c) round; and (d) square hollowpoles.
Fig. 7. SEM micrographs of the microstructures fabricated by microforming with the diamond dies: (a) pyramid; and (b) crossed channels.

Introduction to Micro Metal Forming

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Micro Metal Forming Parts


Micro Metal Forming

Wire Forming and Micro Miniature Forming

Metal Stamping and Forming
Metal Stamping and Forming

A microforming apparatus

Deformed pins showing size effect

Fig. 1: Forming Assembly
Fig. 2: Segmented Dies
Fig. 3: Loading Stage
**Precision Metal Forming**

- Relatively small size
- Dimension accuracy
- Surface quality
- Near net shape
- Net shape

**Review of state of the art in micro forming**

Influence of the grain size and the sample size on the measured strength value

- Researches show that there is a transition from the polycrystalline to single crystal behaviour, if the normalized thickness of the part, i.e. the fraction of part diameter and grain size, falls below a certain value (part diameter/grain size ~ 10), see Fig. 15.
- is detected, if the grain Above that value constant strength size is held constant and the diameter of the samples is varied, as the sample size decreases to dimensions comparable to 10 times the grain size, the region with size effects is entered.
- The typical behaviour of a polycrystal, which is determined by the interaction of dislocations with grain boundaries and described by the Hall–Petch equation, transforms to the behaviour of a single crystal, as the restraints by the grain boundaries diminish.

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Fig. 14. Relation of surface grains to volume grains [27].

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Micro Metalforming with Silicon Dies


Fig. 6. Straight channel structure in AlPcS structure dimension 1 µm

Fig. 7. Silicon die for embossing of stainless steel. Fp = 3000 K, 2D embossing test.
Fabrication of diamond dies for microforming


Fig.6. SEM micrographs of the fabricated diamond dies: (a) pyramids; (b) square poles and crossed wall; (c) round; and (d) square hollow poles.

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精微模具製造技術
Precision Micro Mold and Die Fabrication
Outlines

- 微雷射加工
- 超精密加工
- 微放電加工

微雷射加工(Micro Laser Machining)

- 紅外線雷射
  - 將材料表面物質加熱汽化（蒸發），以除去材料之加工方式，故稱為熱加工。
  - CO₂雷射（波長10.6μm）
  - Nd：YAG雷射（波長1.064μm）

- 紫外線雷射
  - 直接將材料之分子鍵打斷，使分子脫離本體之加工方式，不會產生高熱，故習稱為冷加工。
  - UV-YAG雷射：係將Nd：YAG雷射經非線性倍頻晶體轉換為波長532、355、266、213nm的紫外線雷射。
  - 準分子雷射(Excimer laser)
微雷射加工(Micro Laser Machining)

- 深徑比
  - CO₂雷射：0.4~0.9：1，用於盲孔。
  - UV-YAG：0.25~10：1，通孔、盲孔皆可。

- 孔徑
  - CO₂雷射：150~350 μm
  - UV-YAG雷射：25~150 μm

- 加工精度：以圓孔為例
  - CO₂雷射：150 μm（誤差5 μm）
  - UV-YAG雷射：25 μm（誤差2 μm）

- 加工速度
  - CO₂雷射：300孔／min
  - UV-YAG雷射：24000孔／min
Femtosecond Laser

(http://www.llnl.gov/str/str/Stuart.html)

- Micro Laser Machining
  - Micro-drilling
  - PCB, Filters, Coronary Stents
  - Micro-cutting
  - Coronary Stent Cover, Wire Frame
  - Micro-etching
  - Medical Device Marking, Wire Marking
  - Micro-precision
  - 3D Mold, Micromachining
  - Micro-welding
  - Diodes
超精密加工(Ultra Precision Machining)

- 超精密加工主要係以超精密切削刀具(Ultra Precision Cutting Tool, UPC)來進行切削加工。
- 單晶鑽石刀具
  - 單晶鑽石具有高硬度、優越的熱擴散性和被切削材之低親和性，可做成非常鋒利之切刃等優可適用於鋁、銅等非鐵金屬或非金屬之超精密切削。
  - 單晶鑽石之加工方法則有研磨、超音波加工、劈切割(Cleaving)、鋸切(Sawing)、放電加工及雷射加工等不同方法。

超精密加工(Ultra Precision Machining)

- 超精密加工，
  - 工件旋轉的車床型
  - 刀具旋轉的銑削型
- 基本上都使用氣／液靜壓軸承、線性滑軌來做為旋轉部及直線移動部之結構
- 雷射干涉或光學尺的測長器
- 精密控制器及滾珠導螺桿或線性馬達等驅動系統
- 防振及溫度控制
超精密加工 (Ultra Precision Machining)

- 光電元件
  - 平面透鏡、繞射鏡片、LCD導光板與菱鏡片、光纖連接器、微光柵
- 超精密模具
  - 鏡片射出模
- 精密軸加工
  - 車用傳動軸、工具機主軸
- 微細加工
  - 3D立體模穴、微軸
- 脆性材料加工
  - 磁碟基板加工、晶圓切割

微放電加工
(Micro Electro Discharge Machining)

- WEDG
  - 微電極、微目具、微軸、微螺桿、微探針
- 微孔加工
  - 微噴嘴、濾光板、光罩
- Micro Milling
  - 微模具（模穴、模仁、沖頭）
- 沖壓
  - 可整合微沖壓模具與沖頭成形、微沖壓製程於同一機台上
- 電鍍成形
  - 微細噴嘴等管狀微結構製作
### 硬體設備

#### 微放電加工機
- 機台精度定位精度：±1 μm
- 最小微電極直徑：20 μm

#### 微奈米轉印機
- 均壓装置
  - 壓印力範圍：0~5000 (kgf)
  - 荷重元重現性：< 1% (Full scale)
  - 轉印力控制精度：< 3% (Full scale)
- 溫控單元
  - 最高工作溫度：250(℃)
  - 溫度感測解析度：0.1 (℃)
  - 壓印區溫度變異量：< ±3 (％)

#### 微沖壓機
- 加壓能力-可變範圍：200~2000 N
- 主軸衝程-可變範圍：0~80 mm
- 主軸速度-加壓時：0.01~35 mm/s
- 主軸重複性：±0.01 mm
- 最小移動單位(mm)：1 μm

#### 光學顯微鏡與量測軟體
- Olympus, 1000x
- Digital Camera
- Measuring Software

### 微放電加工

#### 微探針製作
- 最小微電極直徑：20 μm

#### 微模具製作
- 微金屬壓印模
  - 寬度：75 μm
  - 深度：150 μm
微引伸成形

C1100 圆杯直径3mm

C2680 圆杯直径3mm

微冲剪成形

不锈钢，板厚0.05mm，3%

铜，间隙2.5%，45度
冲剪速度35.0mm/s，厚度0.2mm，
压料力0N

铜，间隙9.3%，板厚0.2mm
冲剪速度17.5mm/s，厚度0.1mm，
压料力300N
微齒輪成形

模數皆為0.15
大齒輪28齒
小齒輪14齒
短軸長2mm
總長度為5mm

微壓印成形

金屬微壓印
金屬板材表面製作微溝槽

PMMA
Micro-resist mrl8030
Thickness 250~500 nm
微擠製成形

等徑轉角擠製
晶粒細化

逆向擠製

雙邊擠製

Cup, C1100, Thickness: 0.1 mm, Diameter: 3 mm