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A computation analysis of the influences of die geometry during ECAP

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A Computational Analysis of the Influences of Die Geometry During ECAP

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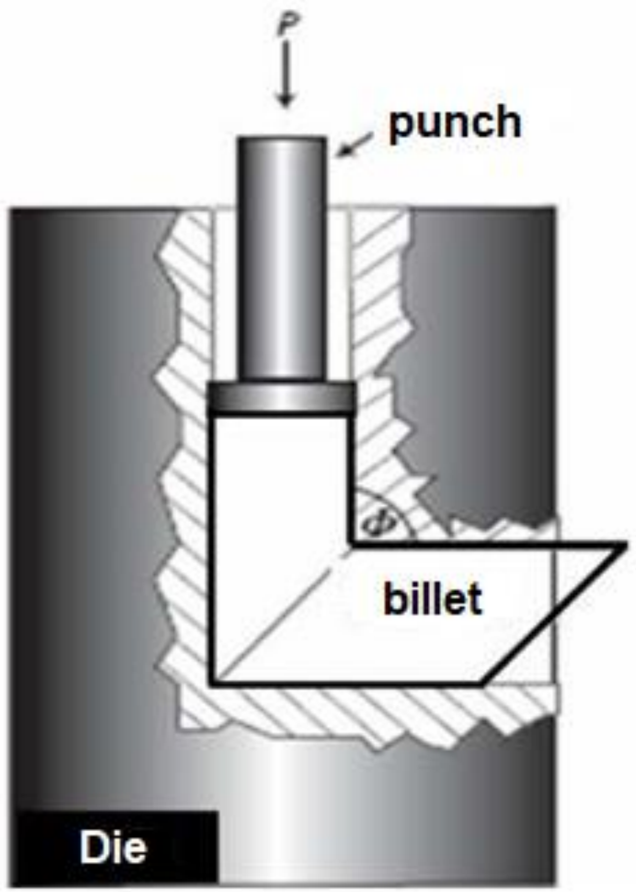
Introduction

- ✓ **Equal-Channel Angular Pressing (ECAP) is a Severe Plastic Deformation (SPD) technique used to produce ultrafine-grained metals**.
  - ✓ Key idea: large plastic deformation without significant change in cross-section
  - ✓ Advantages: grain refinement, improved mechanical properties

- ✓ **Process Overview**

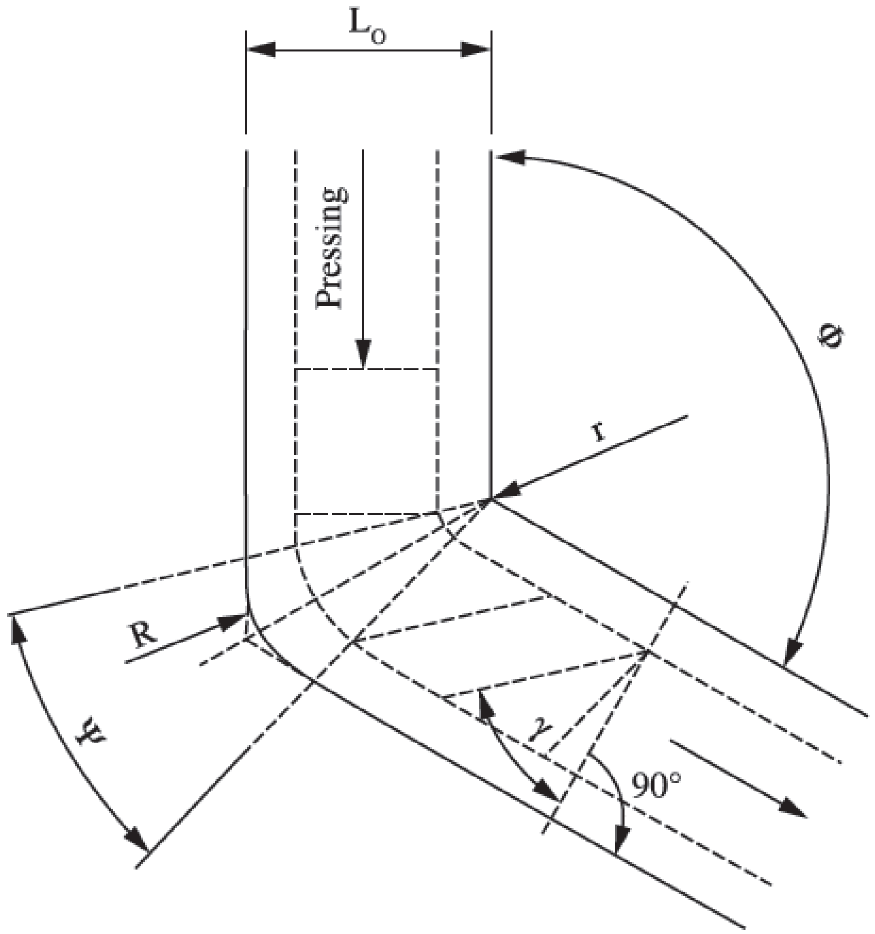


Equal-Channel Angular Pressing (ECAP) Process

Die Geometry

- ✓ **Importance of die geometry:**
  - ✓ Strain homogeneity
  - ✓ Pressing load
  - ✓ Die durability and life

- ✓ **Die geometry parameters:**
  - ✓ Φ: angle between channels
  - ✓ R: external radius
  - ✓ r: internal radius



Geometric characteristics of the ECAP die channels

Objective and Method

- ✓ **Objective:**
  - ✓ Perform a computational analysis of how die geometry parameters affect the pressing load; strain distribution; strain homogeneity and stress concentration in the die

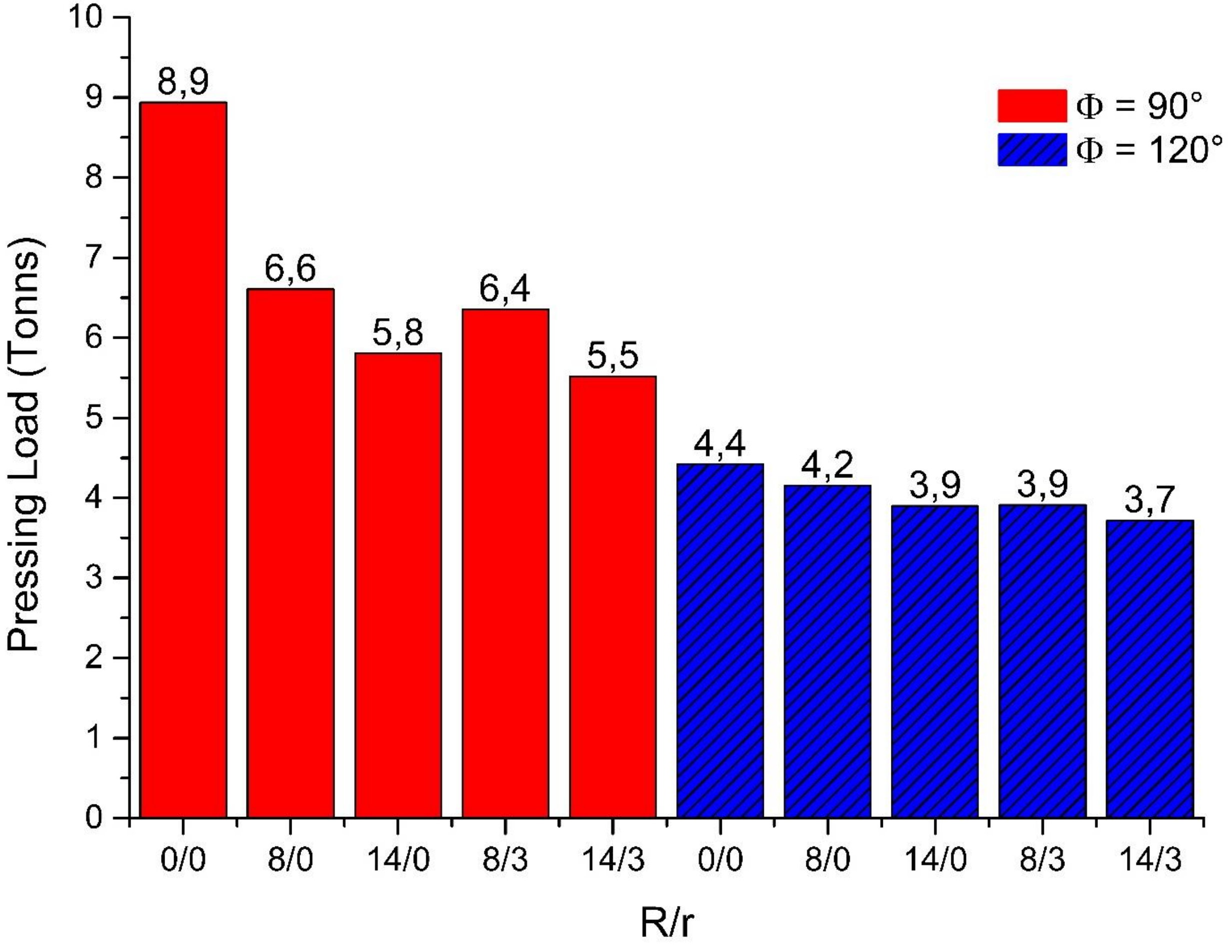
- ✓ **Method:**
  - ✓ Simulations conducted with FORGE NxT 4.0
  - ✓ Materials:
    - ✓ Billet: Al-Cu-Mg alloys (AA2024)
    - ✓ Die: H13 Tool Steel
  - ✓ 10 simulated geometries
    - ✓ First ECAP pass

Name	R (mm)	r (mm)	Φ
Test 1	8	0	90°
Test 2	8	0	120°
Test 3	14	0	90°
Test 4	14	0	120°
Test 5	0	0	90°
Test 6	0	0	120°
Test 7	8	3	90°
Test 8	8	3	120°
Test 9	14	3	90°
Test 10	14	3	120°

Results

Pressing Load

- ✓ Increasing Φ from 90° to 120°
  - ✓ Strong reduction in maximum load.
- ✓ Increasing R also reduces load.
- ✓ Effect of r on load is minor compared to Φ and R

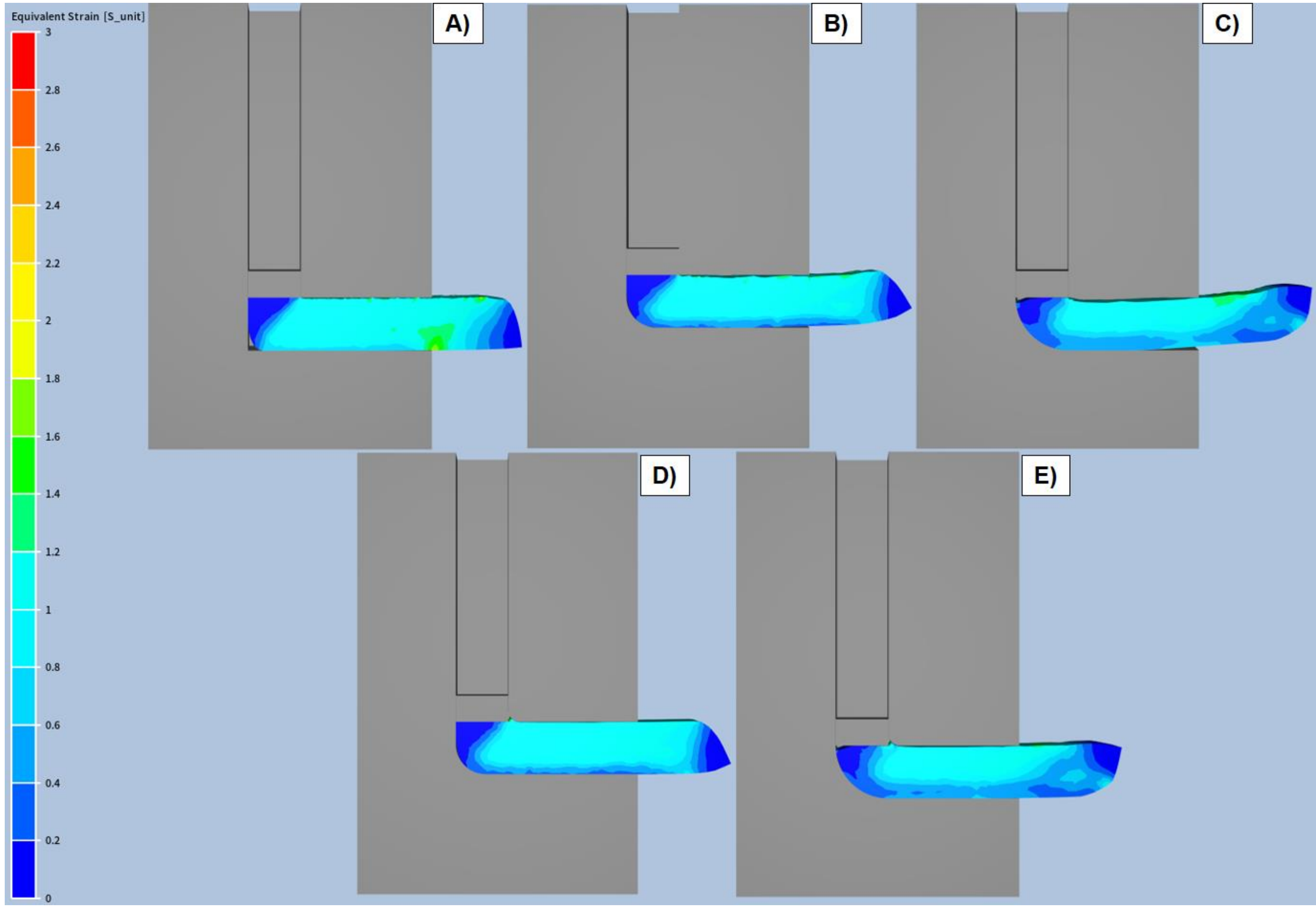


Simulated Maximum Pressing Load for different **R/r** ratios and different channels angle Φ.

Results

Strain Distribution (Φ = 90°)

- ✓ Larger R → lower strain homogeneity across billet.
- ✓ Increasing r → slight reduction in strain at upper billet surface.
- ✓ Larger R increases billet curvature after pressing.

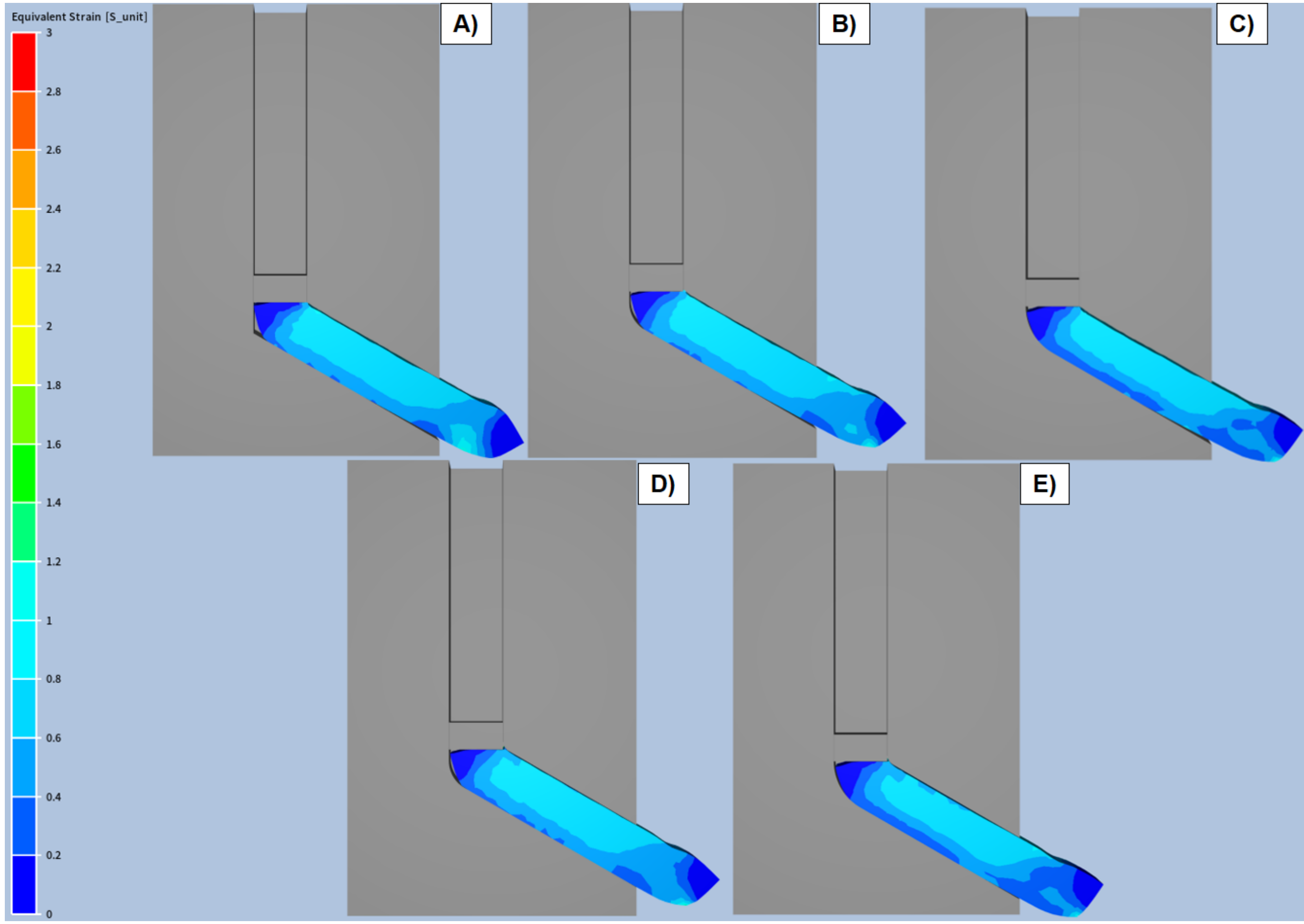


Equivalent strain for different **R**/**r** ratios with a channel angle Φ = 90°.
A) 0/0; B) 8/0; C) 14/0; D) 8/3 and E) 14/3.

Results

Strain Distribution (Φ = 120°)

- ✓ Trends similar to 90°
  - ✓ Smaller r effect.

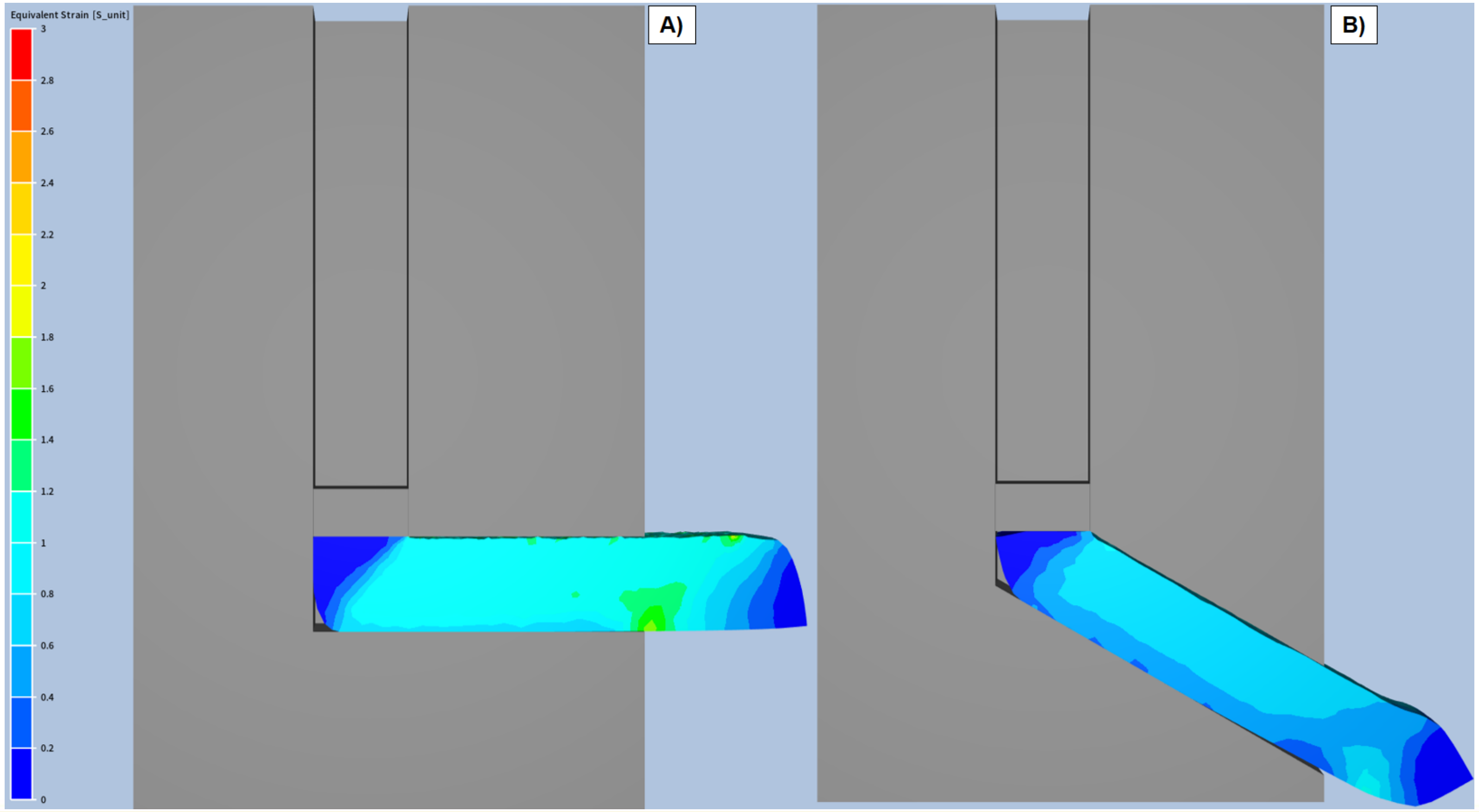


Equivalent strain for different **R**/**r** ratios with a channel angle Φ = 120°.
A) 0/0; B) 8/0; C) 14/0; D) 8/3 and E) 14/3.

Results

Effect of Channel Angle

- ✓ Trade-off between better homogeneity and pressing loads
  - ✓ $\Phi = 90°$ → higher strain levels and better homogeneity, but higher loads.

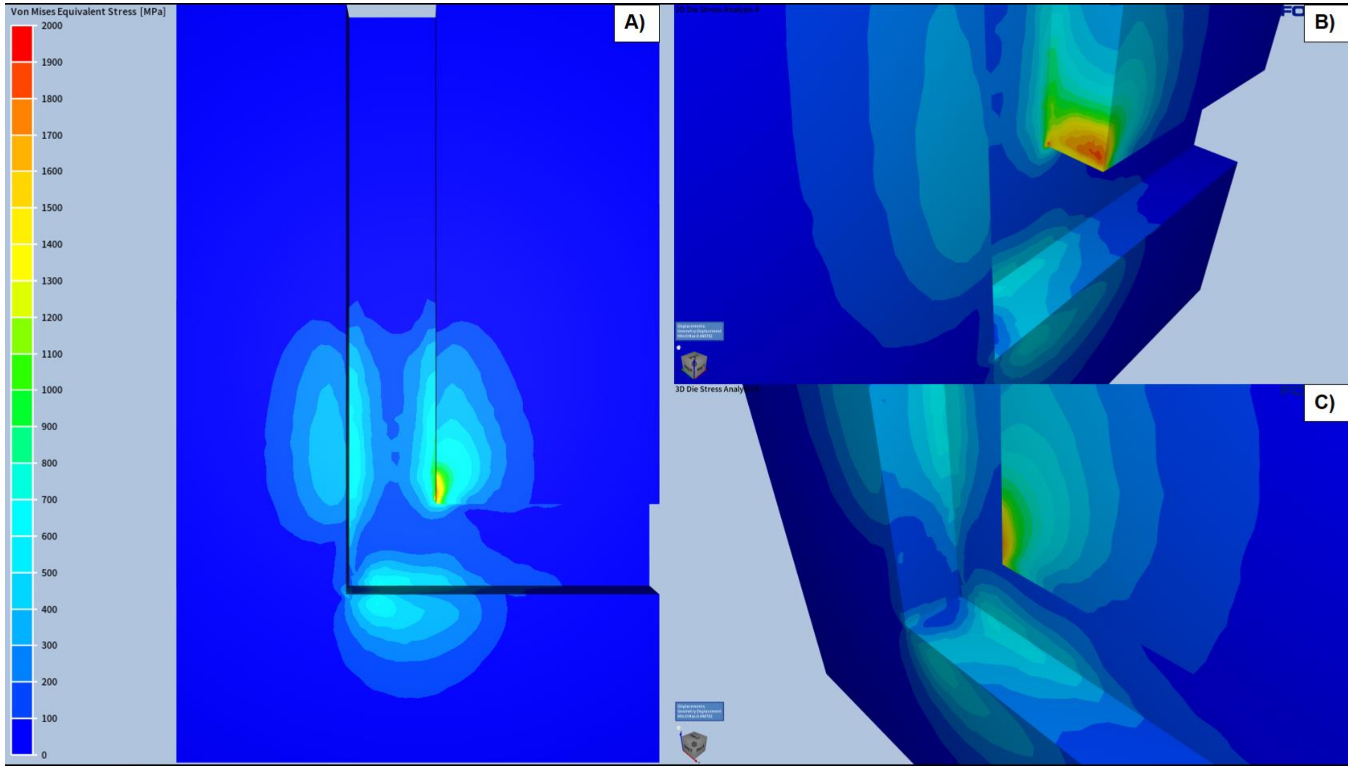


Equivalent strain for $\Phi = 90°$ (A) and $\Phi = 120°$ (B) with **R**/**r** = 0/0.

Results

Die Stress Analysis - Φ = 90° and R/r = 0/0

- ✓ Highest stress concentration
  - ✓ Inner corner region
  - ✓ Peak: 1,400 MPa
- ✓ Sharp-cornered geometry leads to stress accumulation

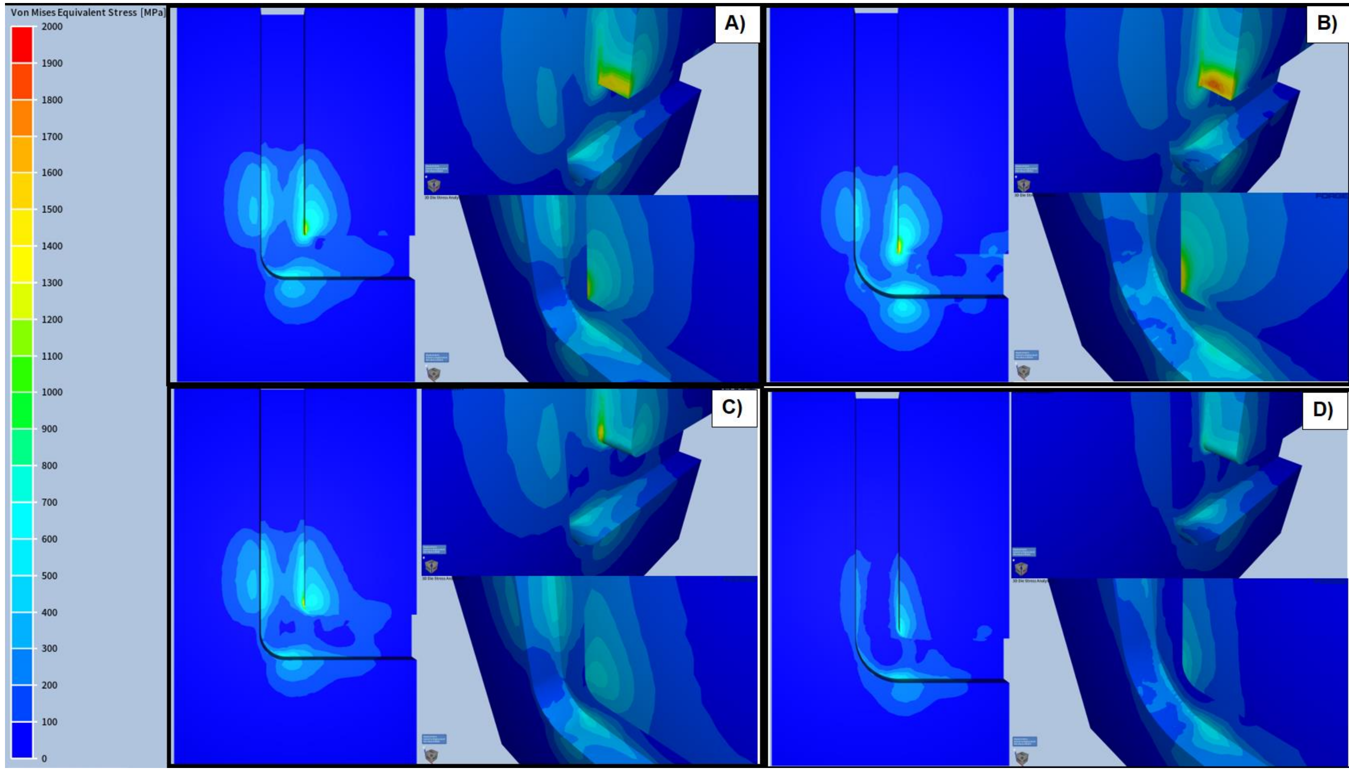


A) Von Mises Equivalent stress for R/r = 0/0 with a channel angle Φ = 90°.
B) and C) Detailed views of the equivalent stress distribution near the corners.

Results

Die Stress Analysis

- ✓ Increasing R and r → reduction in maximum stress
- ✓ Effect of r (inner corner) is more significant in mitigating stress concentration

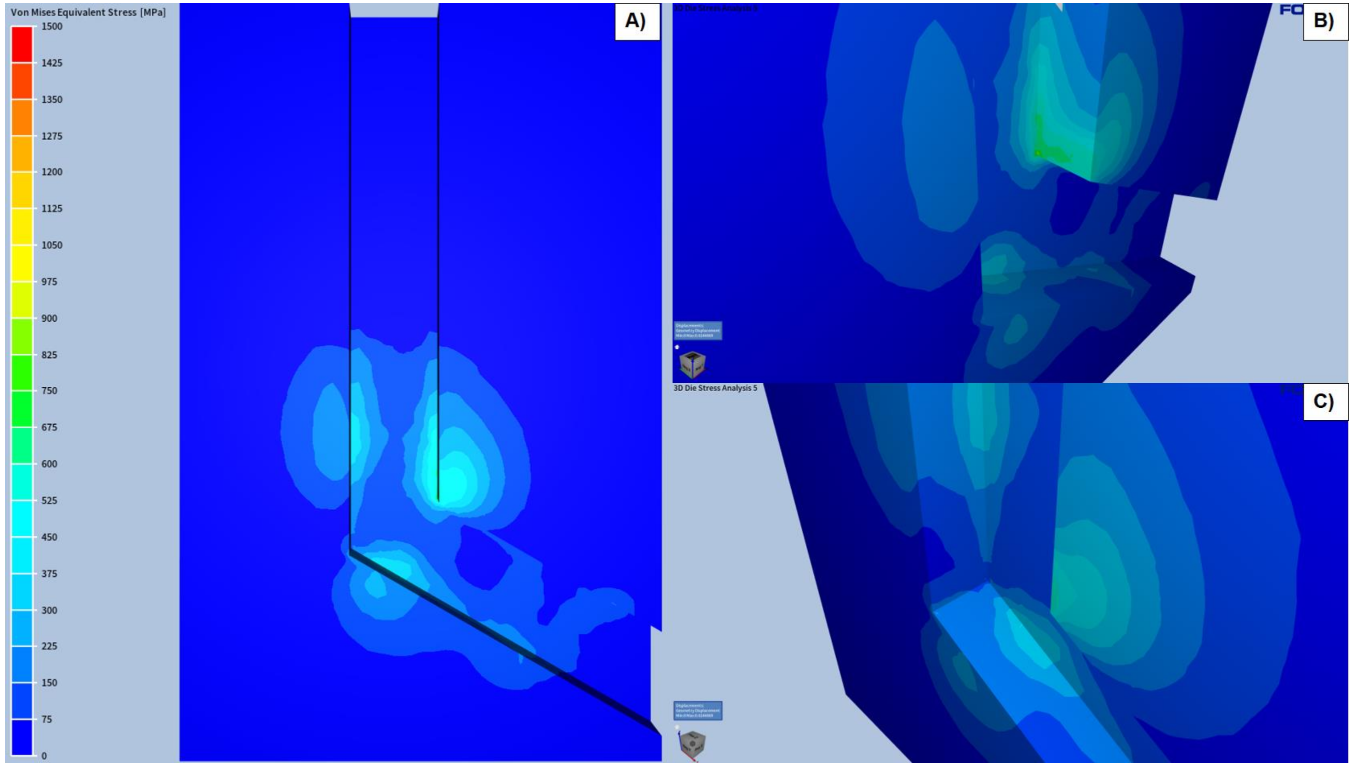


Von Mises Equivalent stress for different R/r ratios with a channel angle Φ = 90°. A) 8/0; B)14/0; C) 8/3 and D)14/3.

Results

Die Stress Analysis - Φ = 120° and R/r = 0/0

- ✓ Noticeable reduction in maximum stress levels → from 1400 MPa to less than 1,000 MPa
- ✓ Lower stress concentration observed at the inner corner
- ✓ Findings align with the reduction in required pressing load

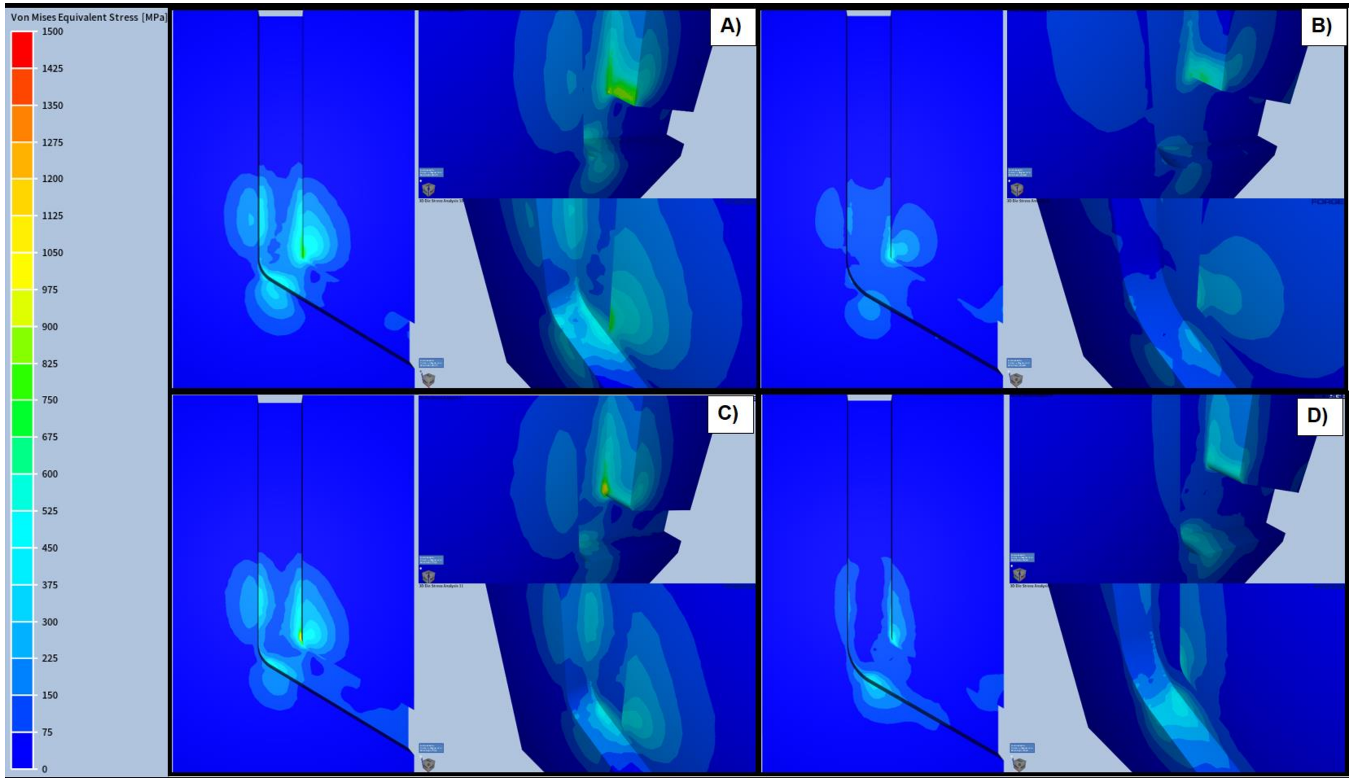


A) Von Mises Equivalent stress for **R**/**r** = 0/0 with a channel angle Φ = 120°. B) and C) Detailed views of the equivalent stress distribution near the corners.

Results

Die Stress Analysis

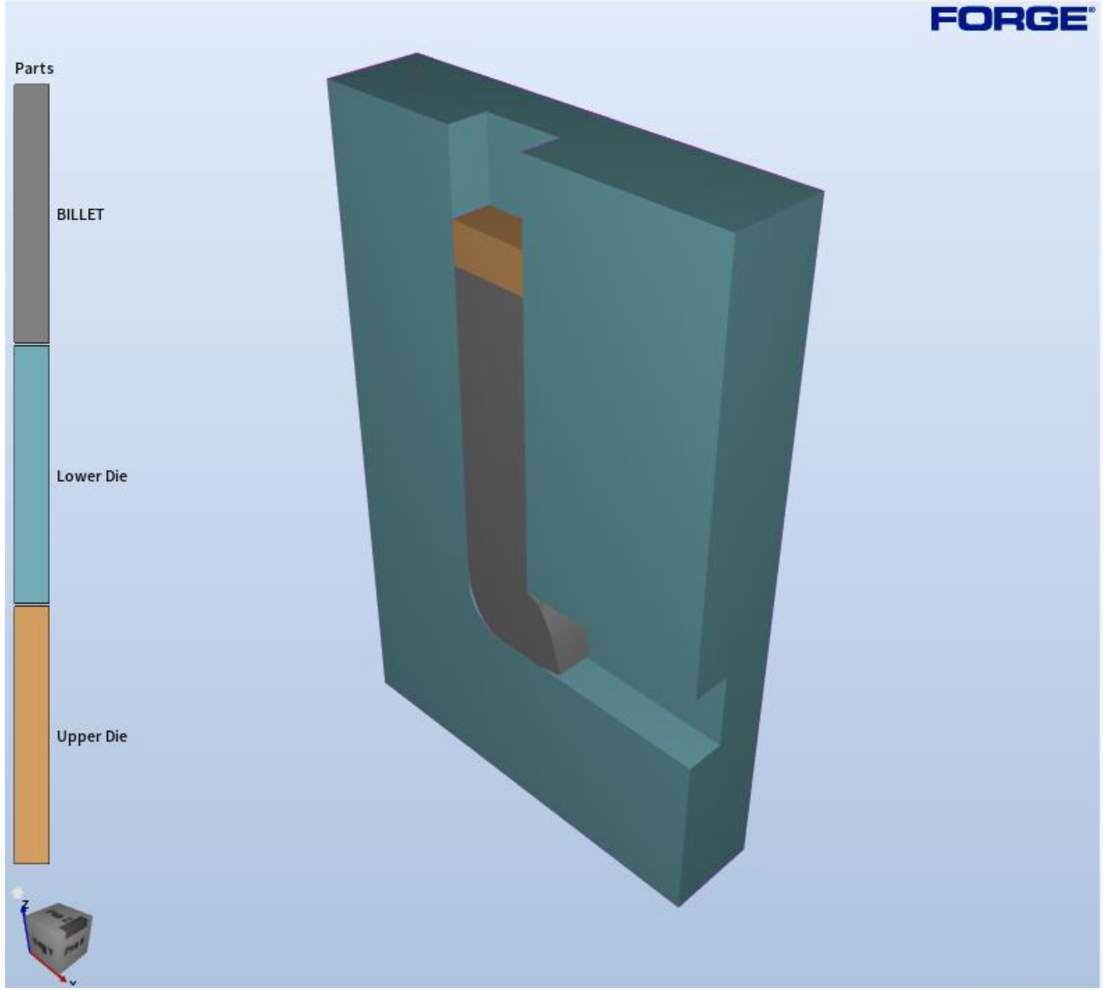
- ✓ Same trend previously observed for Φ = 90°
- ✓ Combined effect larger channel angle (Φ = 120°) and increased radii (R/r = 14/3)
  - ✓ Lower overall stress concentration
  - ✓ 400 MPa and 650 MPa



Von Mises Equivalent stress for different **R**/**r** ratios at a channel angle Φ = 120°. A) 8/0; B)14/0; C) 8/3 and D)14/3.

Trade-offs

- ✓ For low pressing load → increase **Φ** and **R**
  - ✓ Leads to reduced homogeneity
- ✓ For better strain homogeneity → smaller **Φ** and smaller **R**
  - ✓ Results in increased pressing loads
- ✓ For longer die life → larger **Φ**, **R** and **r**
  - ✓ Leads to reduced homogeneity



Conclusion

After conducting different computational simulations aimed at understanding the influence of geometric parameters (Φ, R, and r) on the first ECAP process pass, the following conclusions can be drawn:

- ✓ The **maximum pressing load** reached during the ECAP operation **decreases with increase of Φ (channel angle), R (external radius), and r (inner radius)**
- ✓ Among the three parameters analyzed, the **angle Φ** appears to have the **greatest individual impact on force reduction**, followed by R and then r.
- ✓ While **an increase in the external radius R** leads to a **decrease in the equivalent strain homogeneity** across the billet thickness, the **increase in the inner radius r appears to have little to no effect on strain homogeneity.**
- ✓ The **channel angle (Φ)** influences not only the simulated **equivalent strain homogeneity** but also the **strain levels** themselves; a channel angle of Φ = 90° results in higher equivalent strain levels and greater strain homogeneity.
- ✓ An **increase in the channel angle (Φ)**, as well as **larger values of the outer (R) and inner (r) radii**, result in changes to the **stress state and a reduction in the maximum stress** in critical regions with can **enhance tool durability**.

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TRANSVALOR

Thank you

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