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Formability of metallic materials

: plastic anisotropy, formability testing, forming limit

Current Status of Structural Materials
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Contents

What is formability?

Formability?

: Formability refers to the ability of sheet metal to be formed into a desired shape without necking and cracking

Necking is localized thinning of the metal.

: Once necking begins, the loads on a metal are concentrated in the necked region.

↓

Cracks formed during metal forming

↓

Cracks occur fracture.

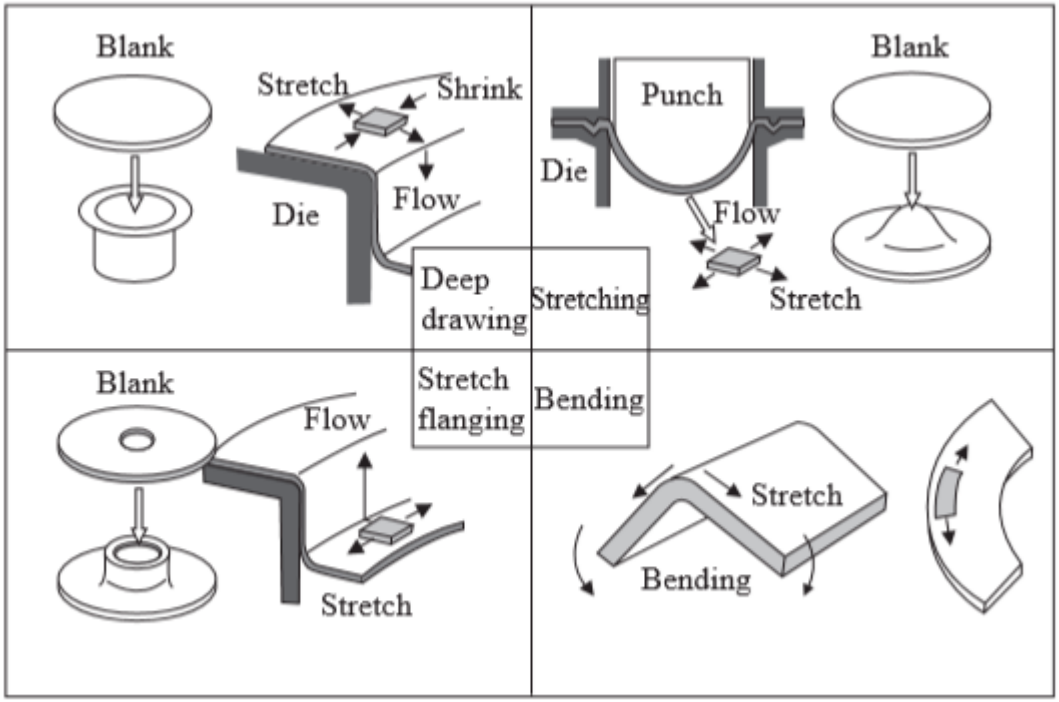
Categories of deformation mode in press forming of sheet steels

In deep-drawing , since the flange part is required to reduce its volume between tools, shrinking is essential for this part.

It is represented by forming limit diagram(FLD)

Stretching aims at securing a domed height while reducing sheet thickness without allowing the fracture of material.

It is represented by limiting dome height(LDH).



Stretch flangeability indicates the formability of the edges.

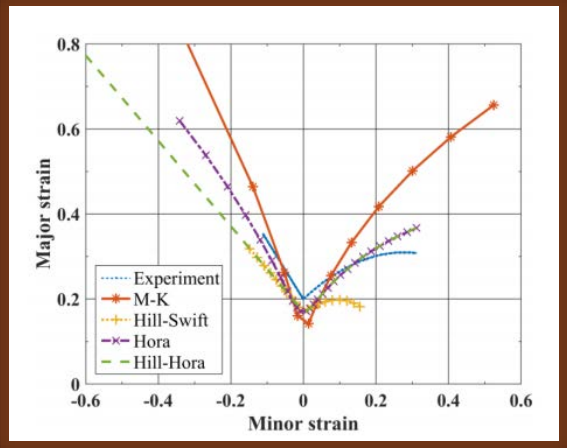
It is evaluated by the hole expanding test in which a pierced hole is expanded with a conical punch.

Bendability can also be construed similar to stretch flangeability as a facture due to a large local deformation.

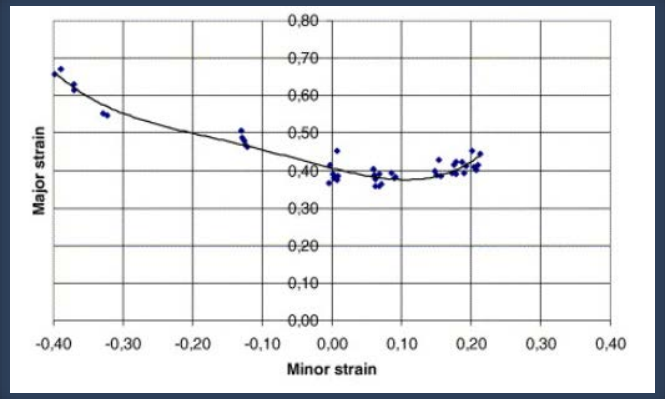
All the parts are formed by a combination of 4 deformation mode

Why it is important to evaluate formability?

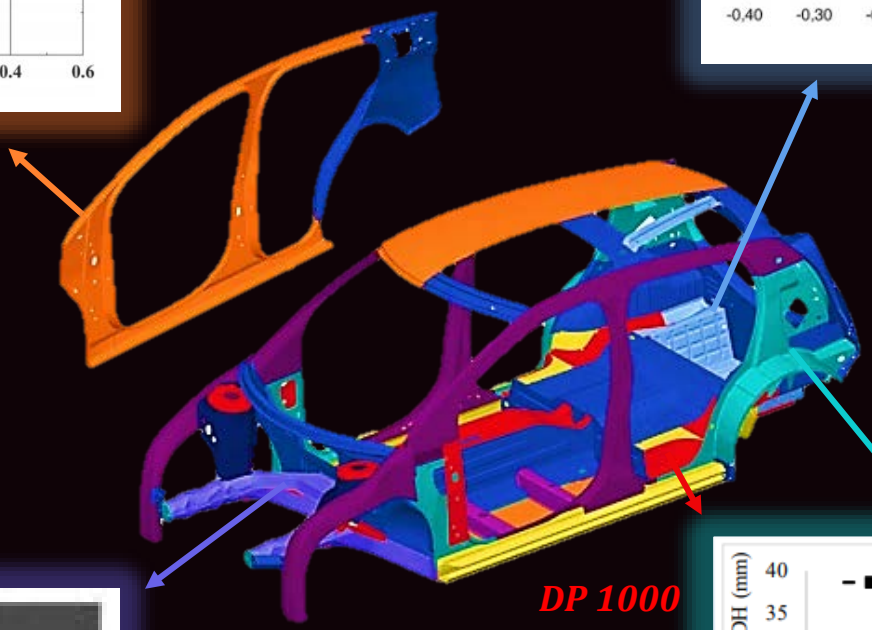
Formability evaluation is essential for using alloys as structural materials.



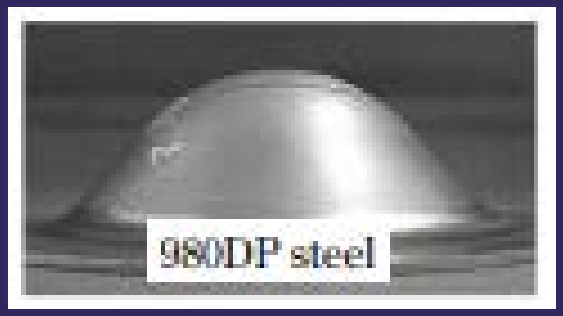
DP 600



Mild steel

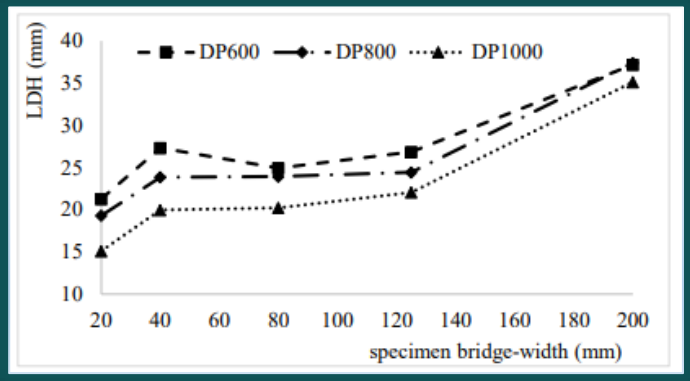


DP 980



DP 1000

DP 800

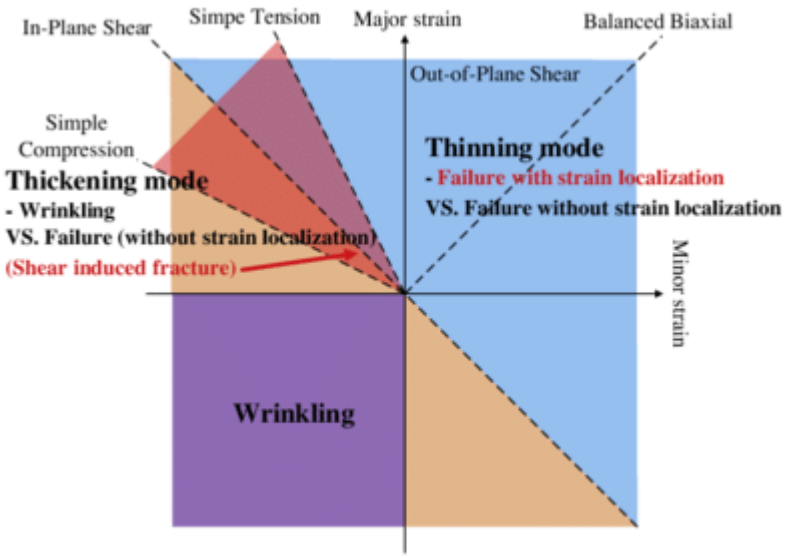


Method for evaluating formability

Formability measurement method

Method 1

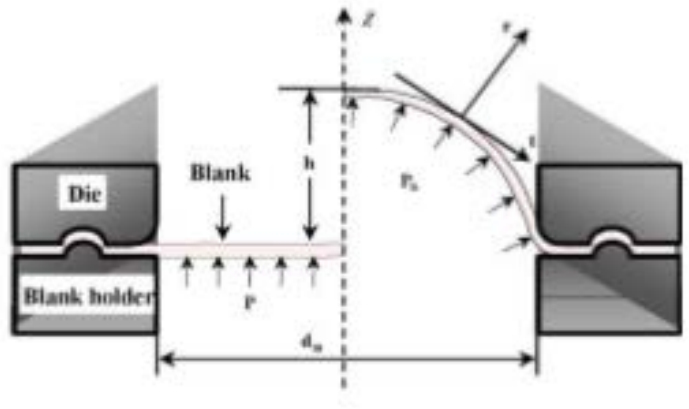
Forming Limit Diagram



Reflect material's drawability

Method 2

Limit Dome Height test



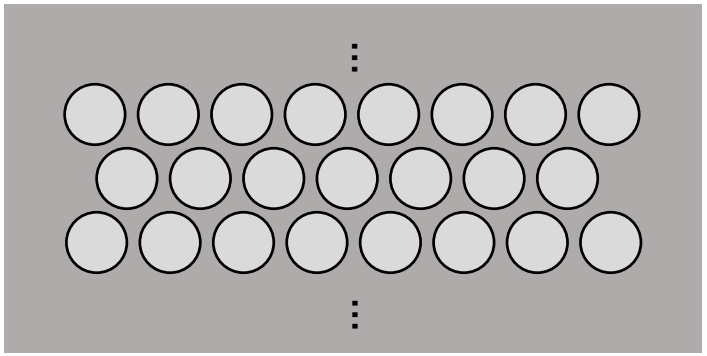
Limit Dome Height ↑ : Good formability

Reflect material's stretchability

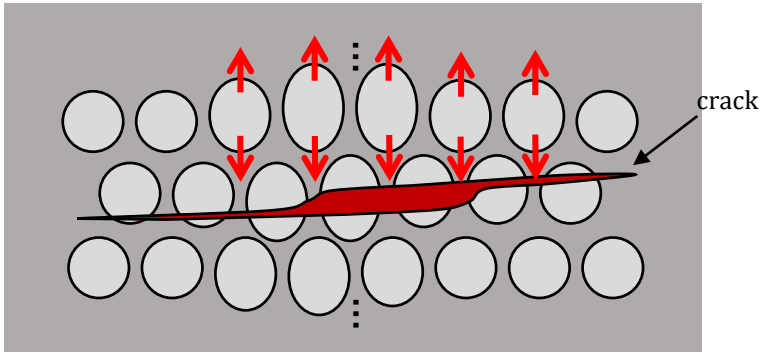
Formability *measurement method 1*: Forming Limit Diagram(experiment)

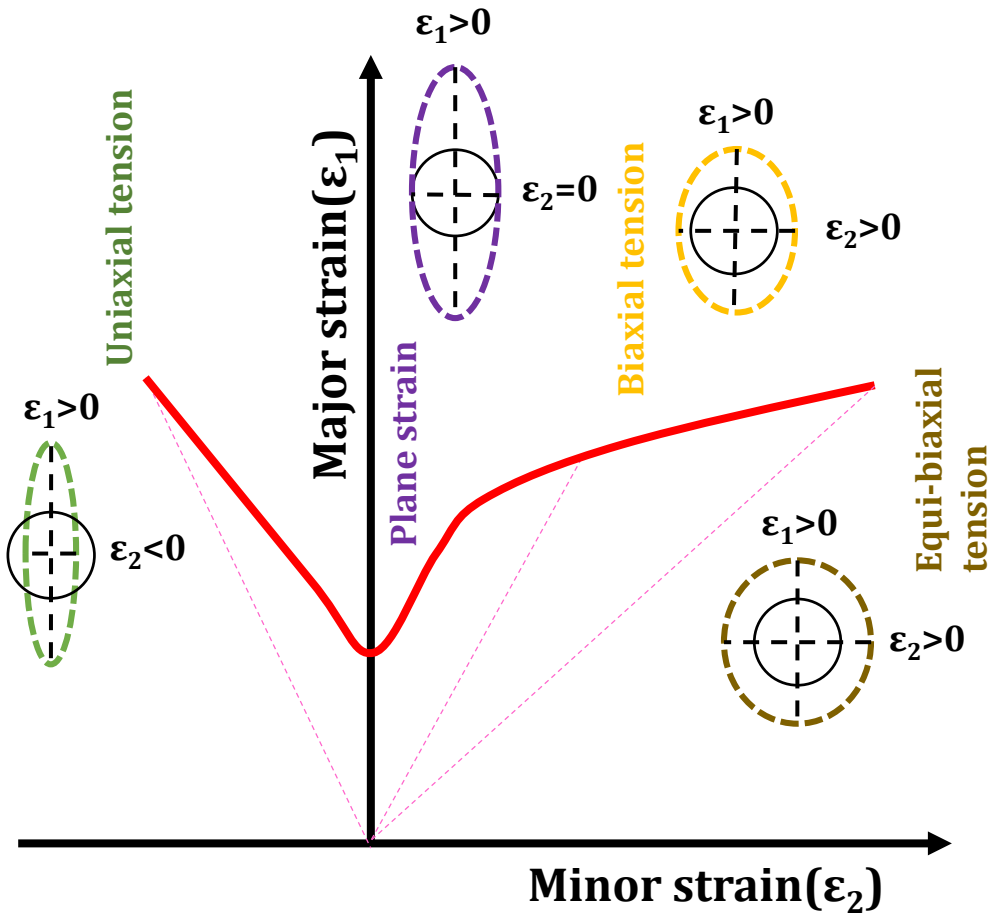
S. P. Keeler, Met. Prog., October 1966, pp. 148-153

Before deformation of sheet

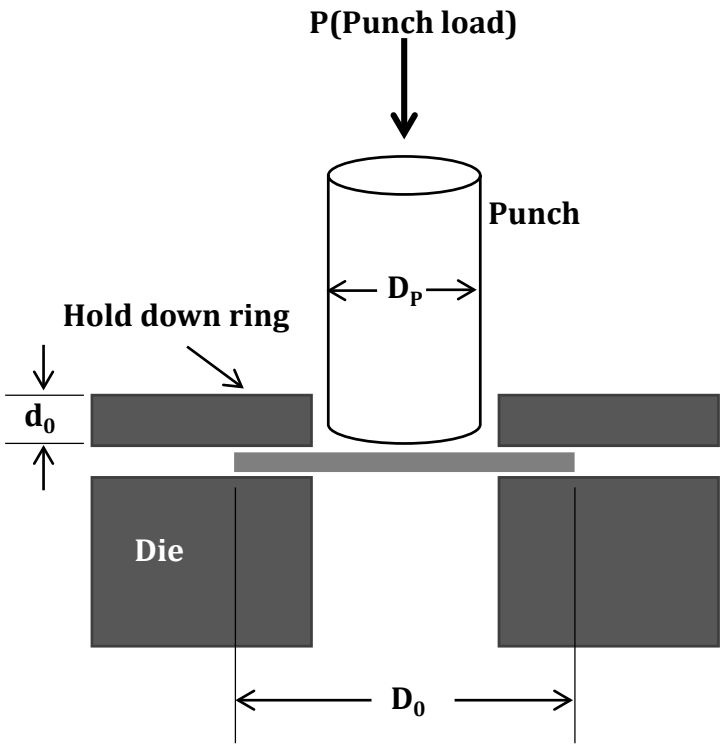


after deformation of sheet

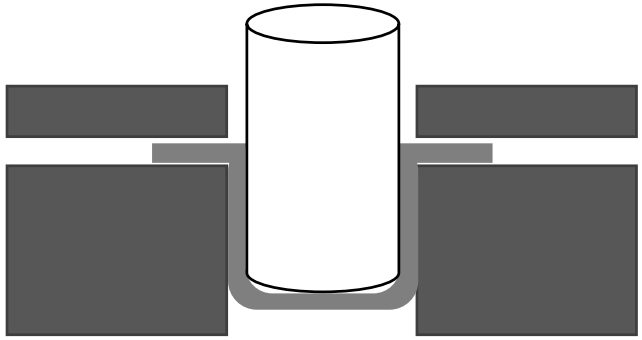




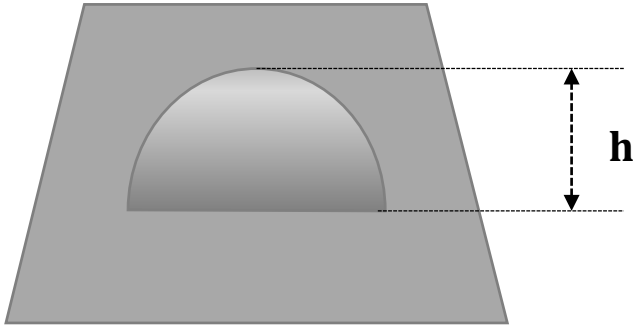
Formability *measurement method 2*: Limit Dome Height test



Before punching



After punching

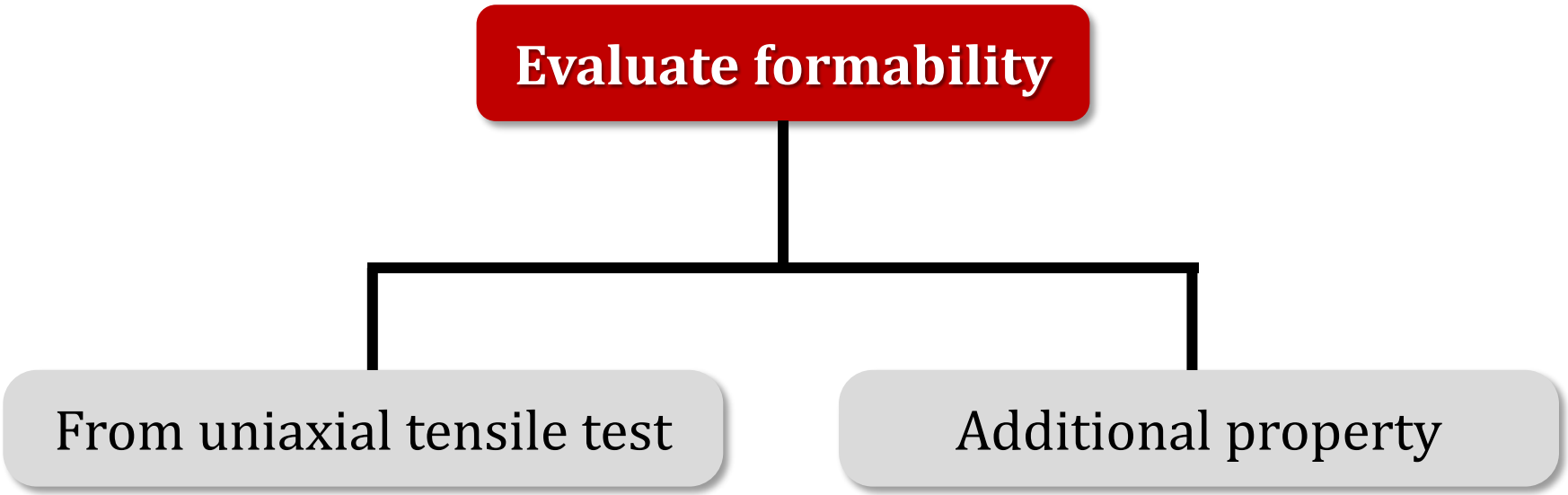


h : Limit Dome Height

- Limit Dome Height is stopped right after fracture occur
- Formability is evaluated by Limit Dome Height value

Formability is determined by relative value of Limit Dome Height

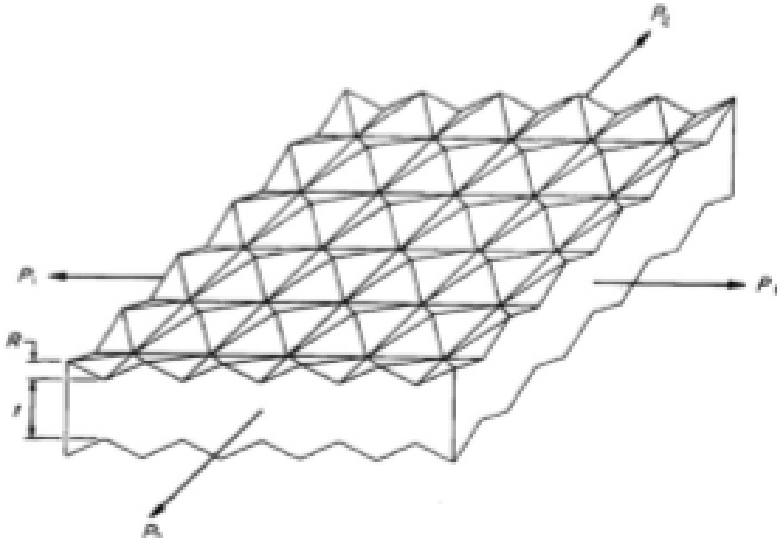
Various factors affecting formability


Evaluate formability
From uniaxial tensile test
Additional property
• Yield stress ↓
• Ultimate tensile stress ↑
• Uniform elongation ↑
• Strain hardening ↑
$\sigma = K\sigma^n$, $d\sigma/d\varepsilon = nK\varepsilon^{n-1} = \sigma$
or
$\varepsilon = n$
onset of necking occur at
strain = strain hardening exponent
• Plastic instability
• Localized necking
• R-value
• Strain rate sensitivity
…

Plastic instability: Surface roughness

When a sheet material undergoes plastic deformation, **microscopic inhomogeneities are present** due to **grains having different orientations.**

Inhomogeneities lead to development of **roughness** on the sheet surface.

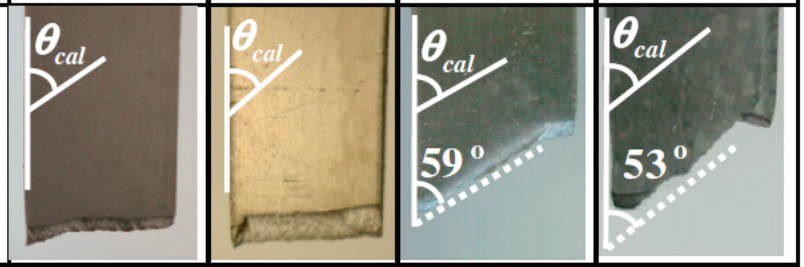


It was demonstrated experimentally that the **surface roughening** significantly affects forming limits of sheet materials, especially, very thin sheets.

$$R=R_0+kd_0\Sigma$$

R: Surface roughness
R_0: initial surface roughness
d_0: average grain diameter
Σ: equivalent strain
k: constant

Formability tendency effected by additional property_TWIP940

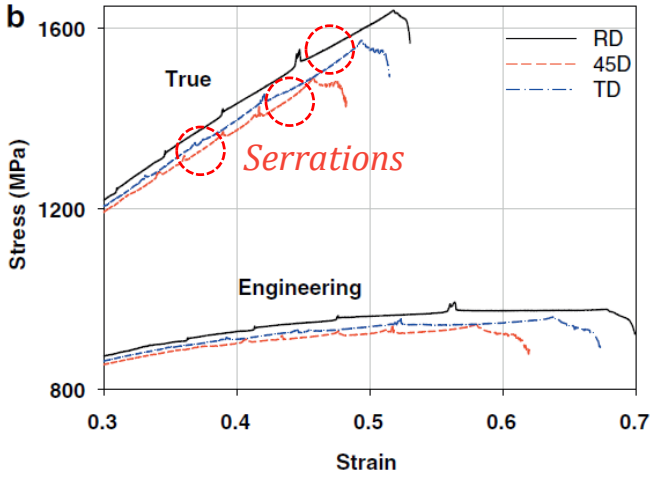
	Failure without stain localization		Failure with stain localization	
Material	TWIP940	AZ31B	AA5083-O	DP600
Thickness	1.47 mm	2.00 mm	1.60 mm	1.50 mm
m value	-0.007	0.008	-0.004	0.009
R_0 value	0.816	2.717	0.524	1.002
Calculated θ	56.16°	49.47°	59.61°	54.72°
Top view				
Side view				

Fail without strain localization

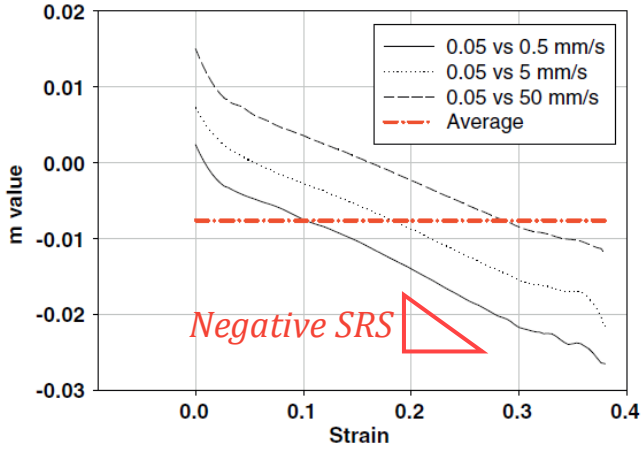
\+

Negative strain rate sensitivity

K. Chung et al./ *International Journal of Plasticity 27(2011)52-81*



Magnified dynamic strain aging section of tensile curve of TWIP940



Variation of the m value of the TWIP940 steel with respect to strain and strain rate.

Fail without strain localization, strain rate sensitivity(m): → Different formability

Definition of formability:

Formability refers to the ability of sheet metal to be formed into a desired shape without necking and cracking

Method for evaluating formability

(1) Forming Limit Diagram

(2) Limit Dome Height test

Various factors affecting formability

(1) Plastic instability: Surface roughening

(2) Localized necking

(3) R-value

(4) Strain rate sensitivity

Thank you for your kind attention

$$F=\sigma A$$

The condition for maximum load can be expressed as,

$$dF = \sigma dA + A d\sigma = 0$$

Rearranging,

$$d\sigma/\sigma = -dA/A = d\varepsilon$$

or

$$d\sigma/d\varepsilon = \sigma$$

since

$$\varepsilon = \ln(1 + e),\ d\varepsilon = de/(1 + e)$$

$$d\sigma/de = \sigma/(1+e)$$

$$\sigma = K\sigma^n,\ d\sigma/d\varepsilon = nK\varepsilon^{n-1} = \sigma, \text{ or } \boldsymbol{\varepsilon = n}$$

Thus, the maximum load, the tensile strength, and the onset of necking occur at a strain equal to the strain-hardening exponent