Die Design Software and Simulation Technology Experience

The Influence of Material Properties on Die Design

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Precision Metalforming Association

The Influence of Sheet Metal Properties on Metal Stamping Die Design

Die

Press

Product

Lubrication

10,000 different combinations

Material

100,000 combinations

The Influence of Sheet Metal Properties on Metal Stamping Die Design

Who is the customer for the sheet metal?

Engineering Department?

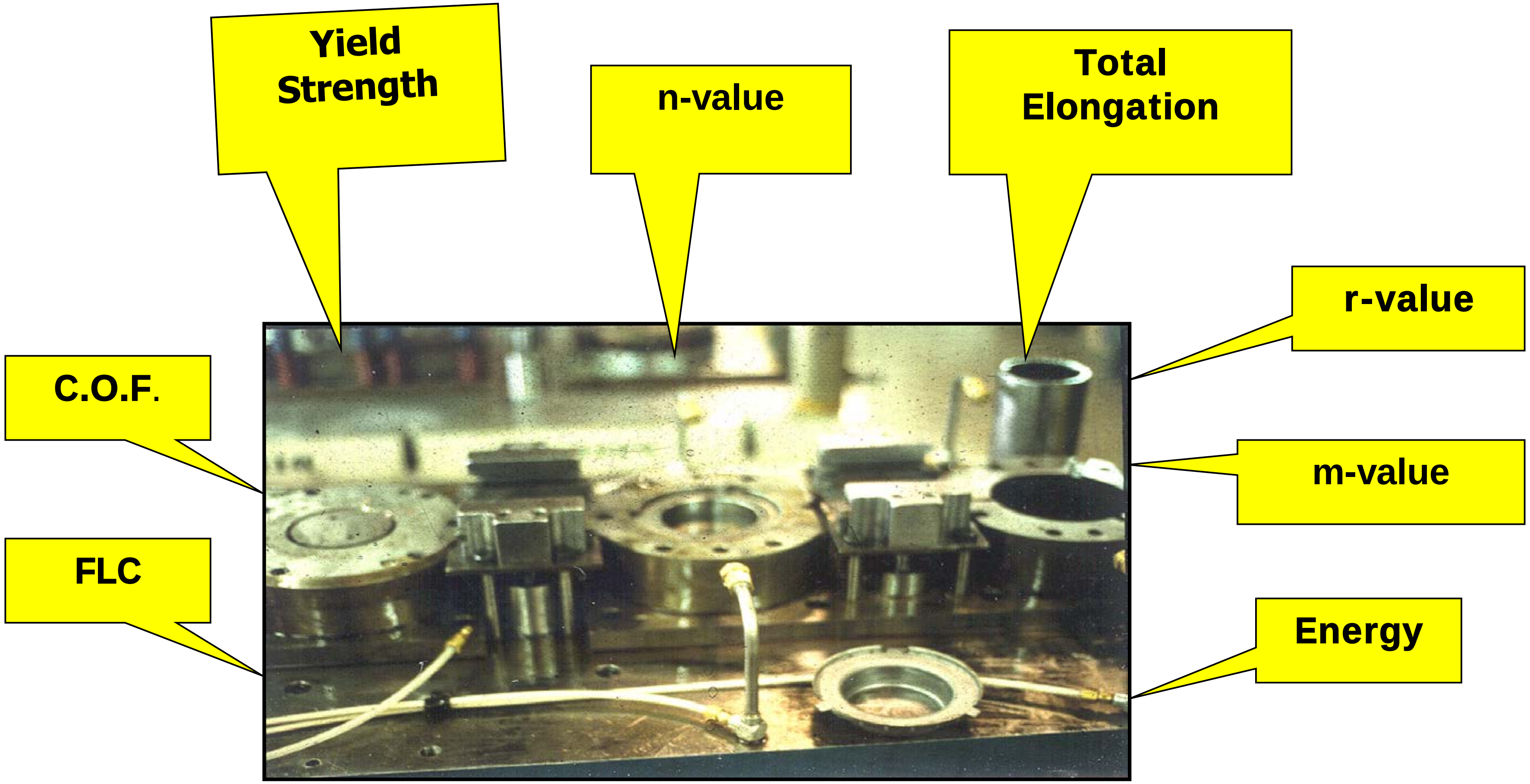
Purchasing Department?

Product Development?

Assembly Plant?

End User?

The Influence of Sheet Metal Properties on Metal Stamping Die Design

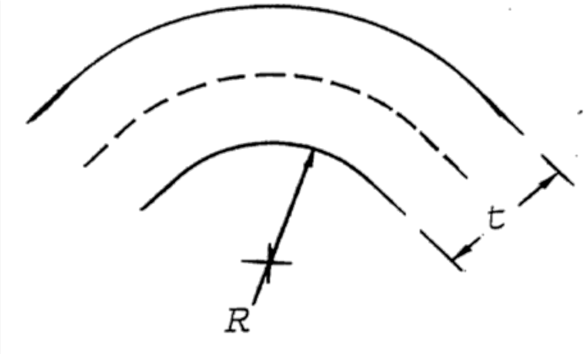


The Influence of Sheet Metal Properties on Metal Stamping Die Design

- **<u>BENDING</u>** is related the **total elongation** of the steel during uniaxial tension testing

$$\varepsilon_{outer} = \frac{1}{2(r/t)+1}$$

$$\varepsilon_{outer} = \frac{1}{2(20/1)+1} = \frac{1}{41}$$



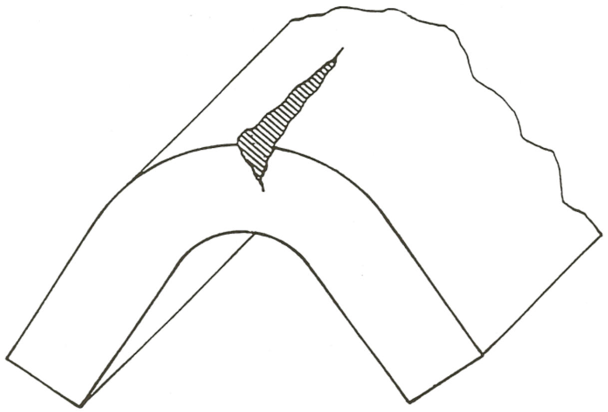
<u>OUTER SURFACE STRAIN CALCULATIONS</u>

for *t* = *1.0*

R/t = 20	Engineering Strain = **2.4%**
R/t = 10	Engineering Strain = **4.8%**
R/t = 5	Engineering Strain = **9.0%**
R/t = 1	Engineering Strain = **33.0%**
R/t = 0.5	Engineering Strain = **50.0%**

The Influence of Sheet Metal Properties on Metal Stamping Die Design

Shear Edge Damage



Shearing damage reduces the total elongation capacity at the edge of the bend; thus, increasing the allowable R/t bend ratio at which edge cracking begins.

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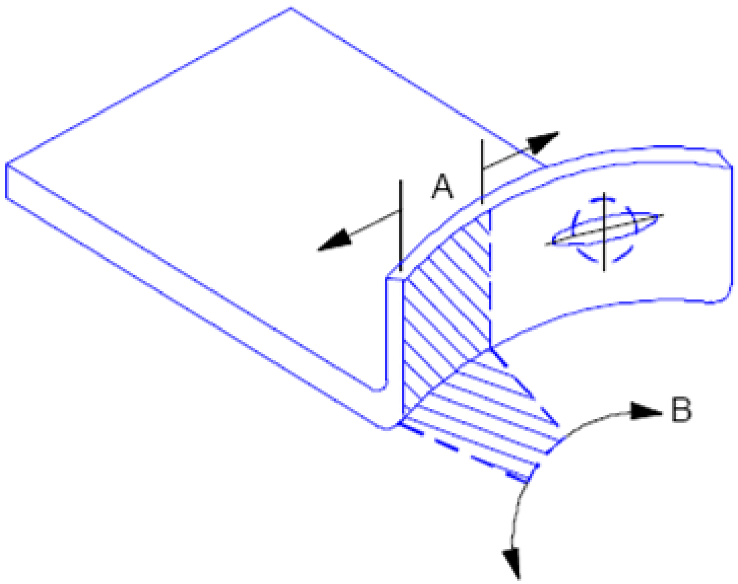
Shear Edge Damage



Stretch flanges have a high potential for splits

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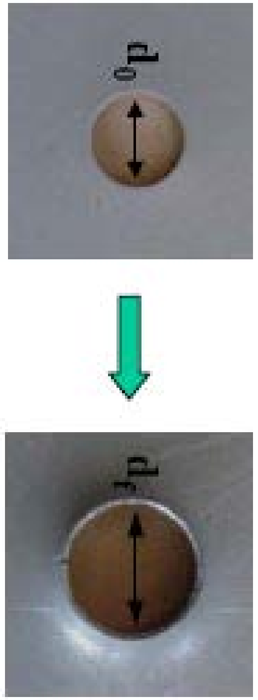
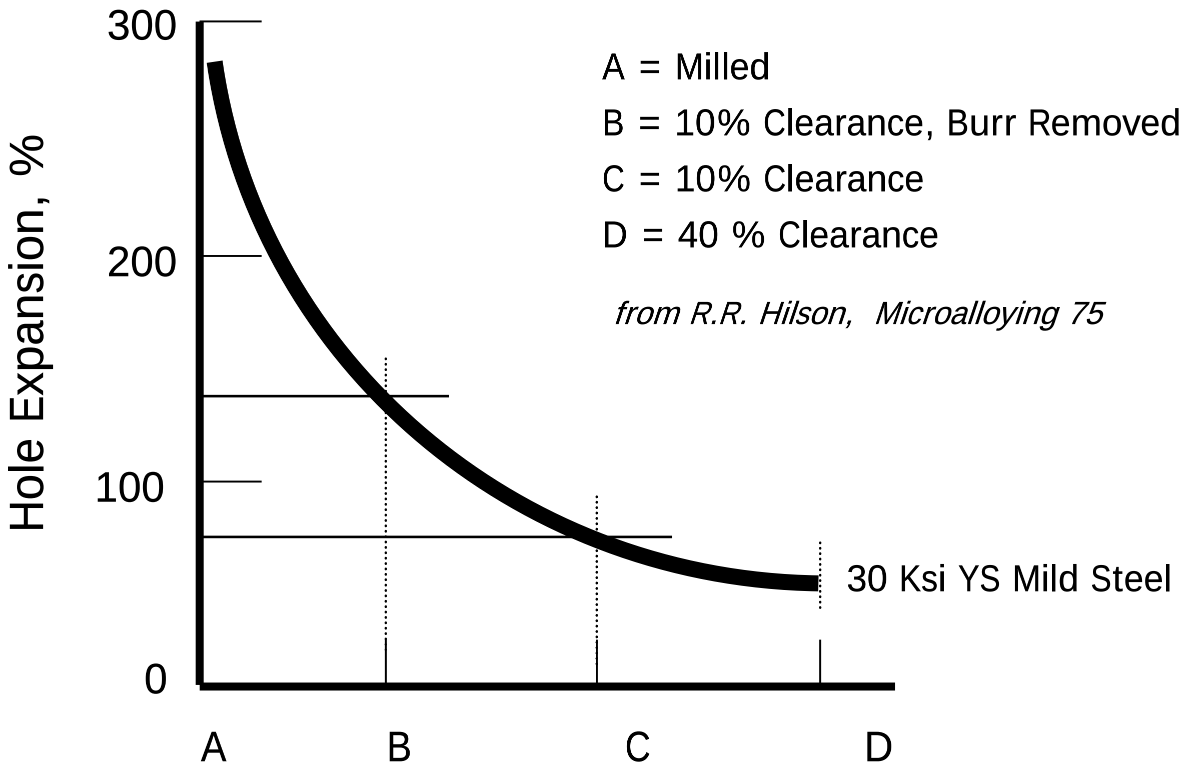
Shear Edge Damage





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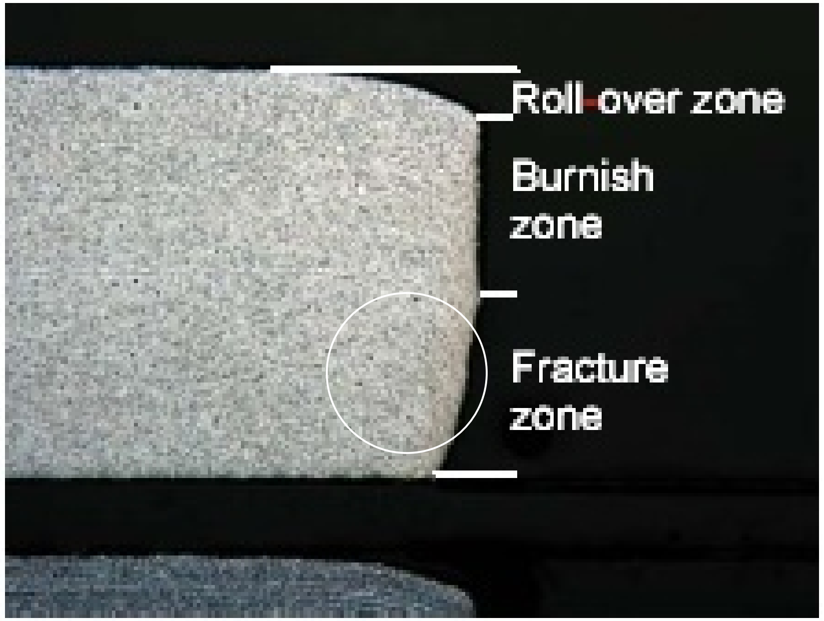
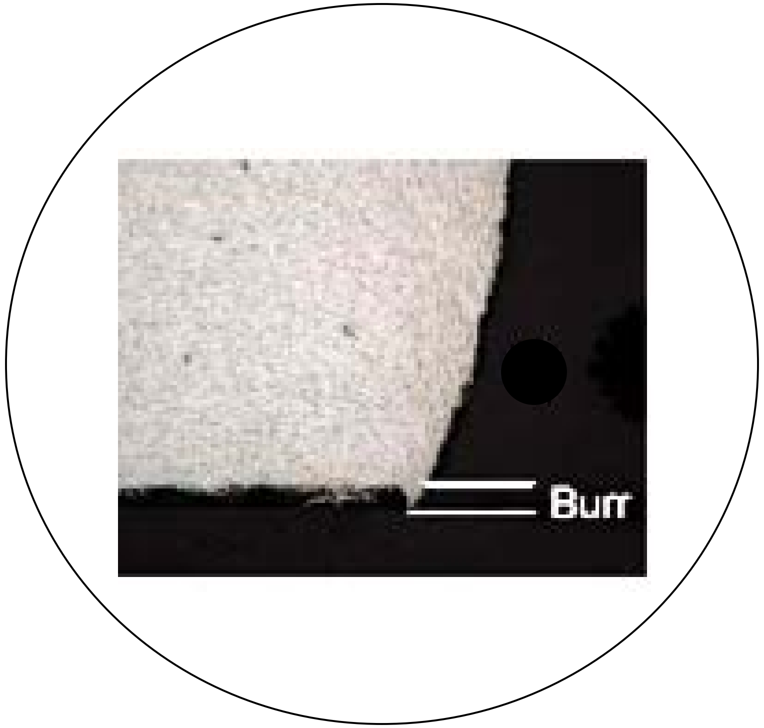
Anatomy of a Sheared Edge





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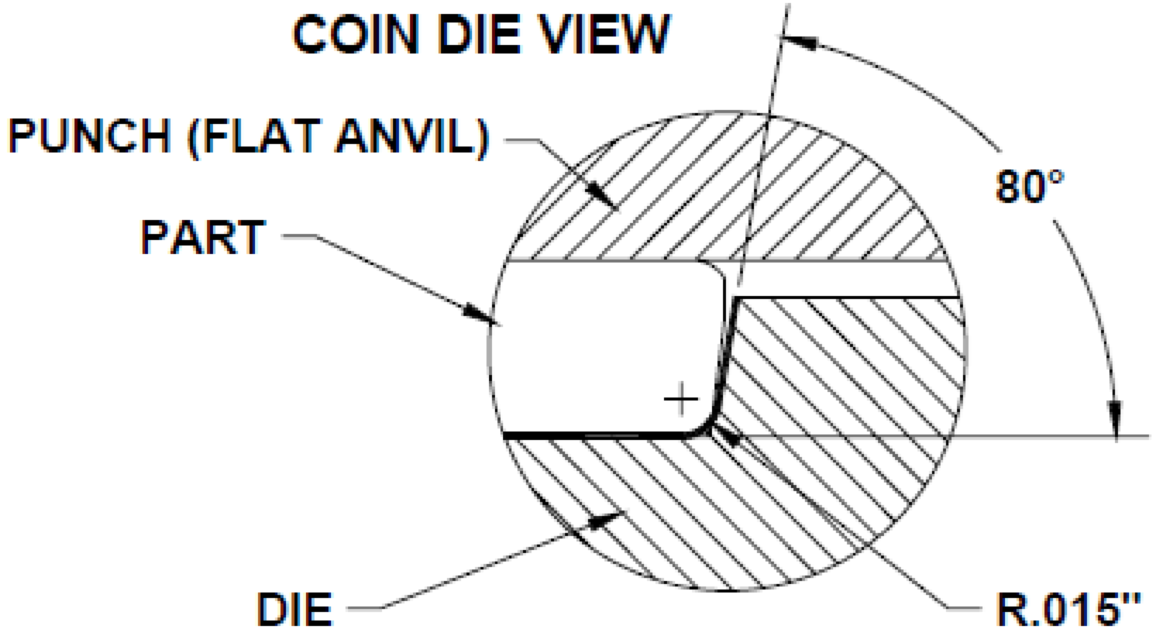
Shear Edge Damage



The Influence of Sheet Metal Properties on Metal Stamping Die Design

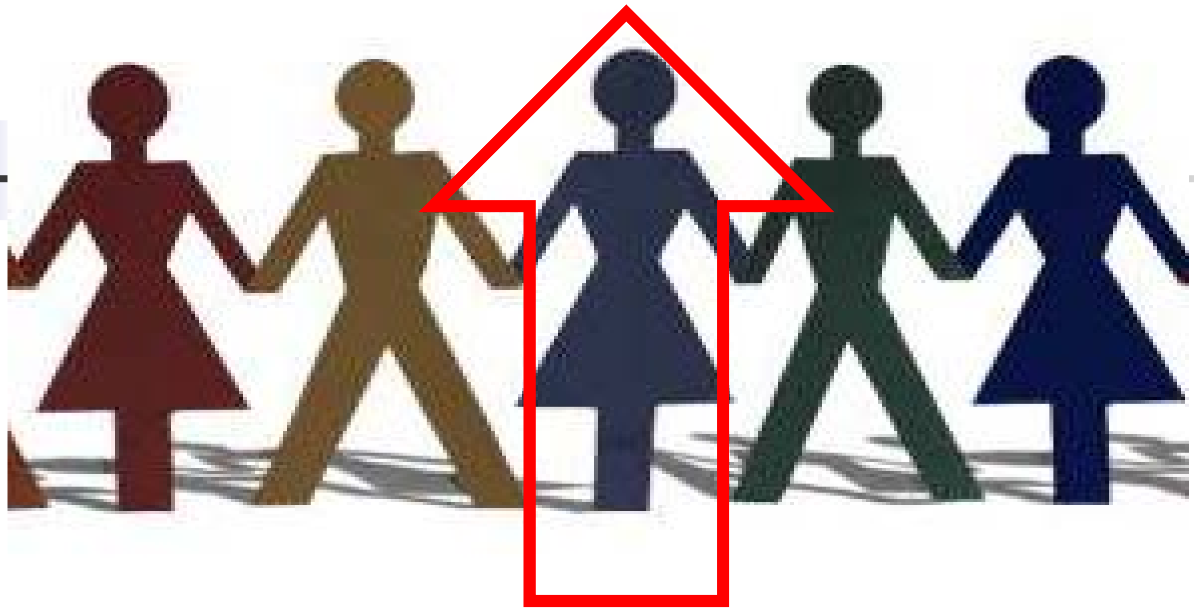
- **STRETCHING** is related to the **n-value**, or work hardening capacity, of the material

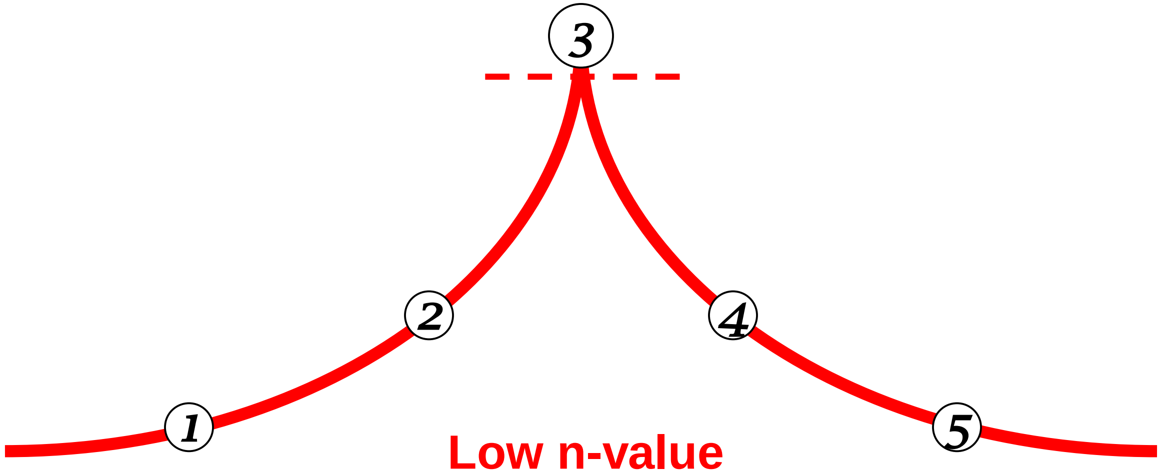
Image: Courtesy Tower International

Material Response to Stress

Work Hardening Exponent: n-value

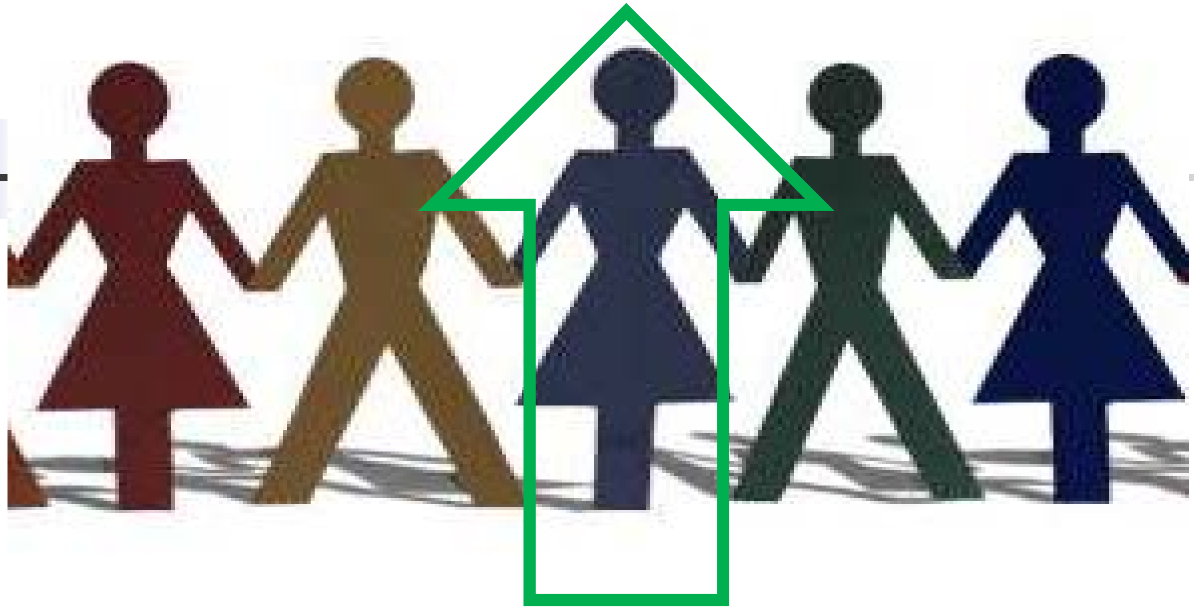
Low n-value

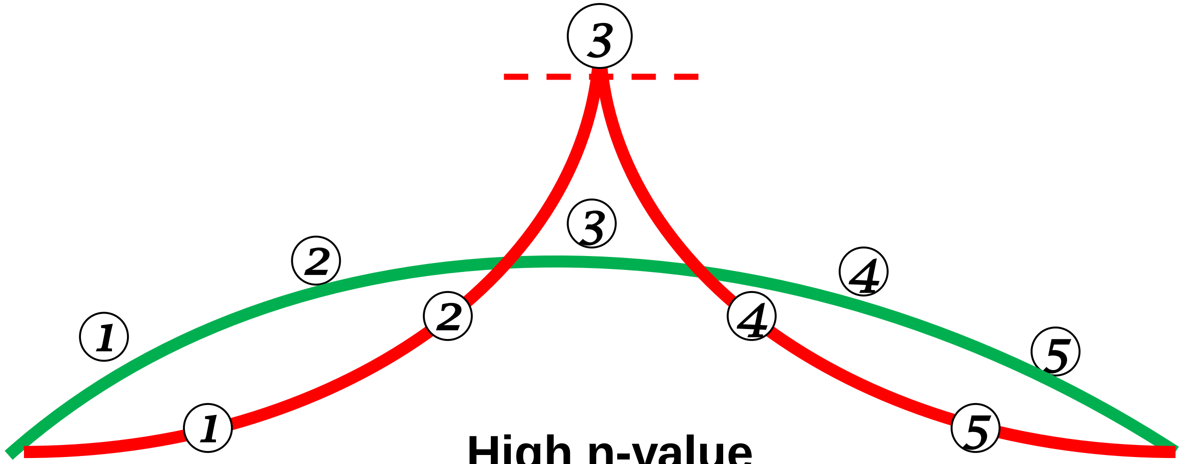




Low n-value

High n-value

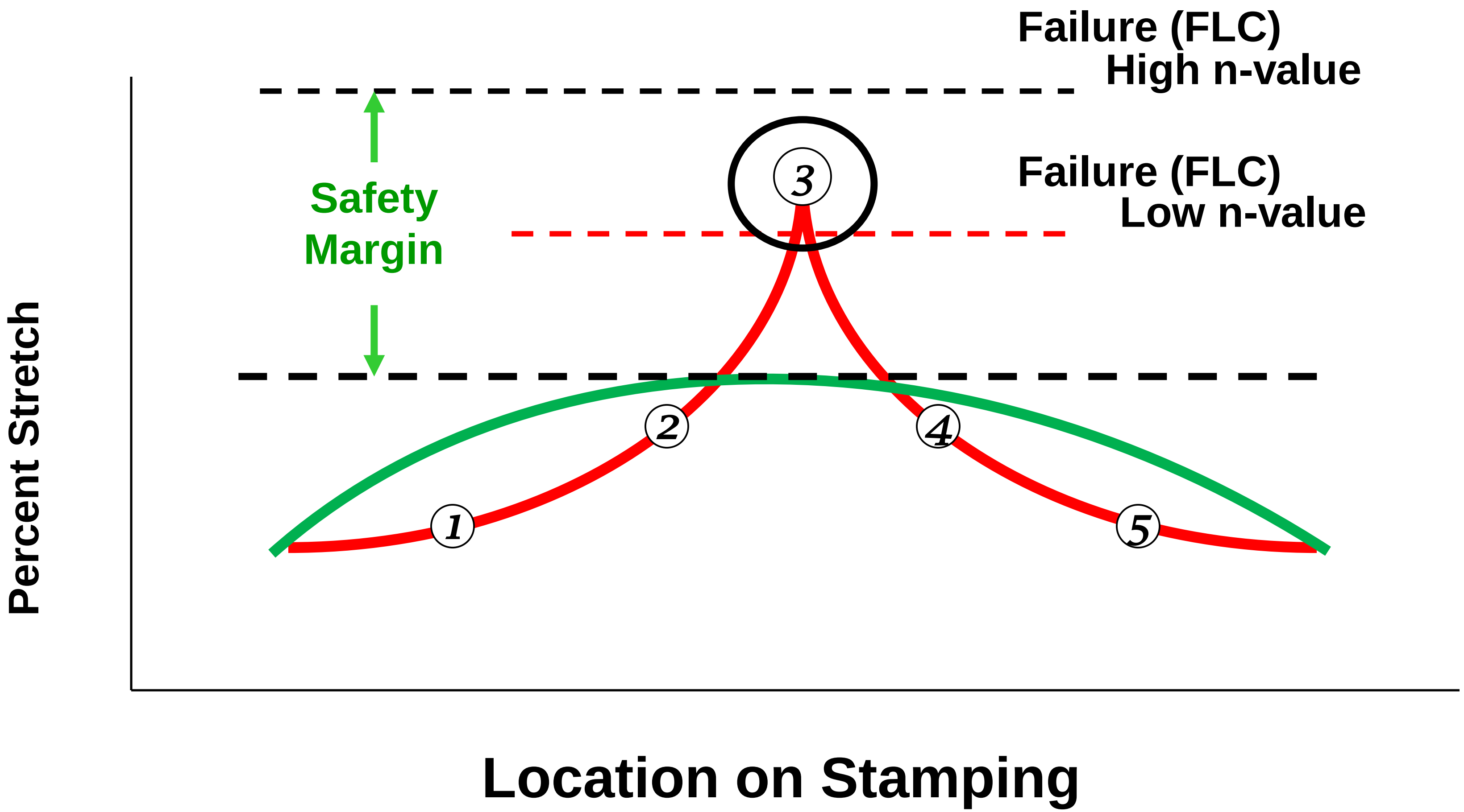




High n-value

Material Response to Stress

Strain Gradients and n-value

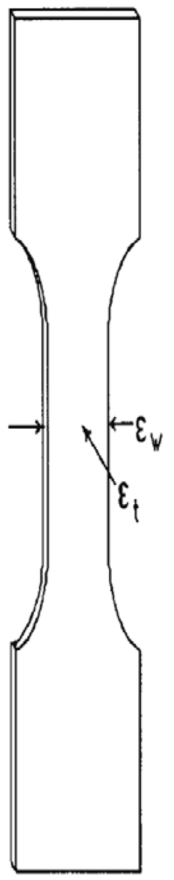


The Influence of Sheet Metal Properties on Metal Stamping Die Design

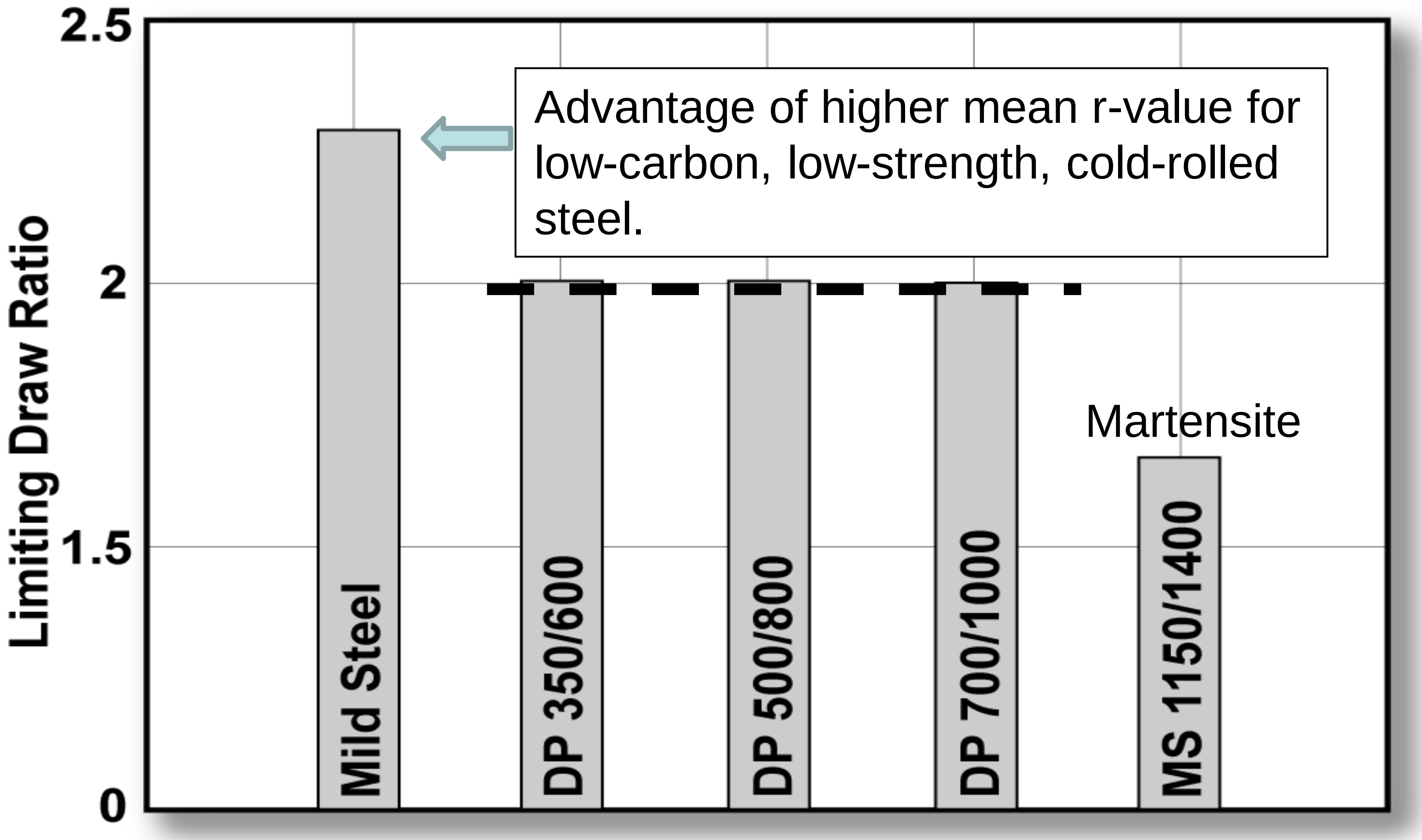
- **CUP DRAWING** is related to the **r-value** of a material, or its plastic strain ratio, it is independent of material strength and n-value

The r-value is defined as the ratio of width-to-thickness strain ($r = \varepsilon_w/\varepsilon_t$)

It describes the material's ability to resist thinning

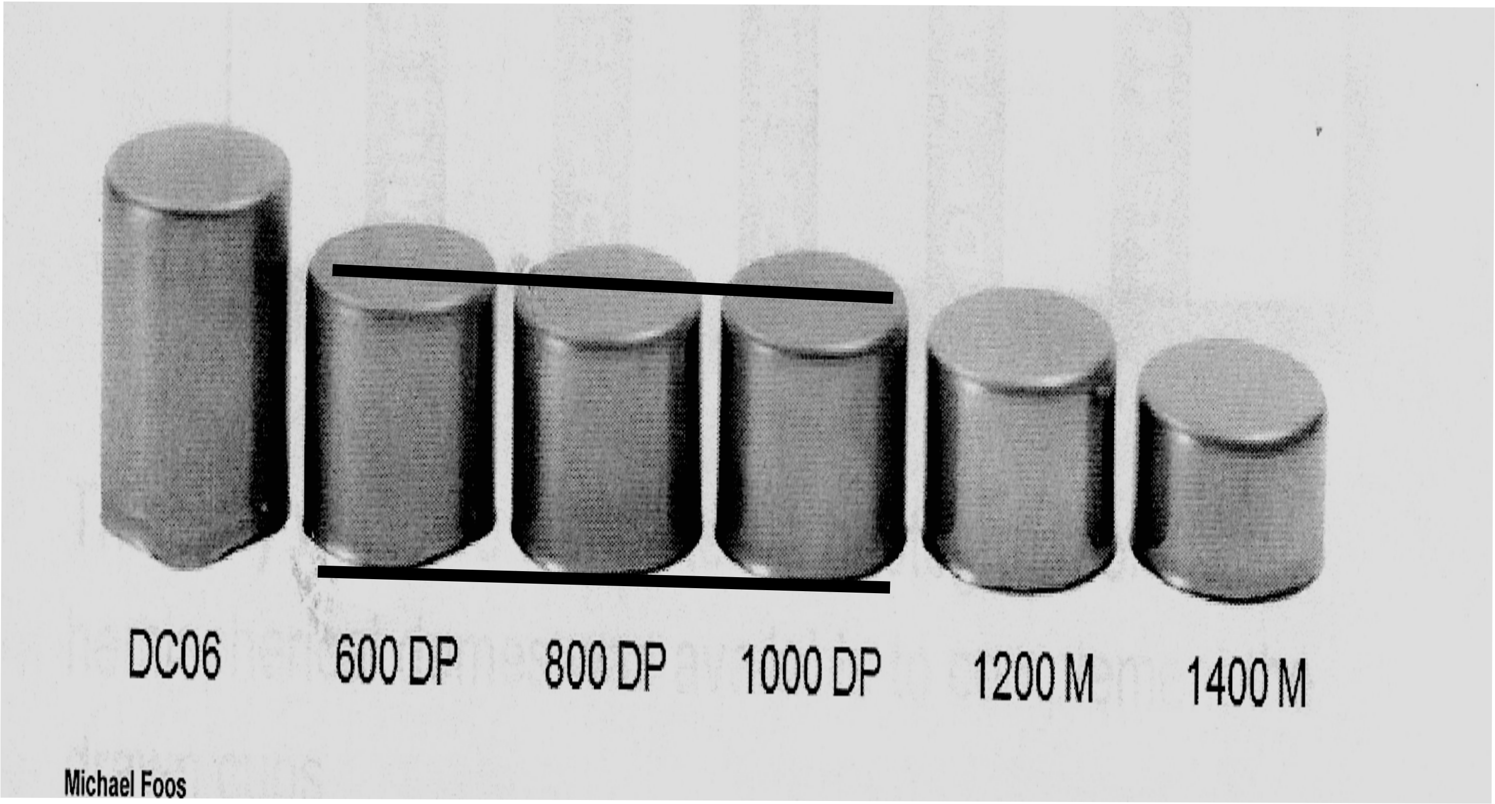


The Influence of Sheet Metal Properties on Metal Stamping Die Design



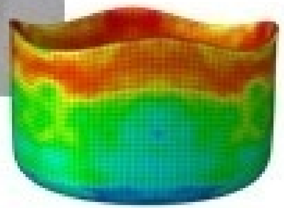
WorldAutoSteel - AHSS Application Guidelines Ver.5.0

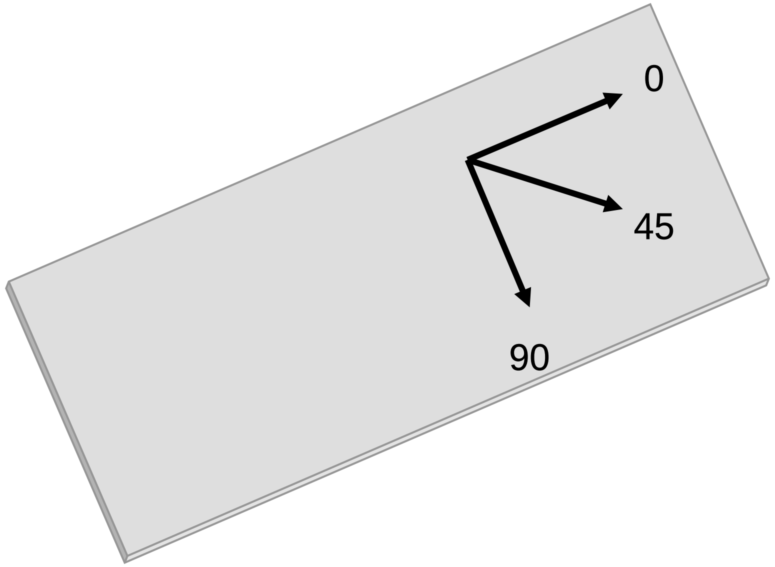
The Influence of Sheet Metal Properties on Metal Stamping Die Design



The Influence of Sheet Metal Properties on Metal Stamping Die Design

Planar anisotropy, common in cold rolled steels, is responsible for the “earring” effect in cup drawing operations.

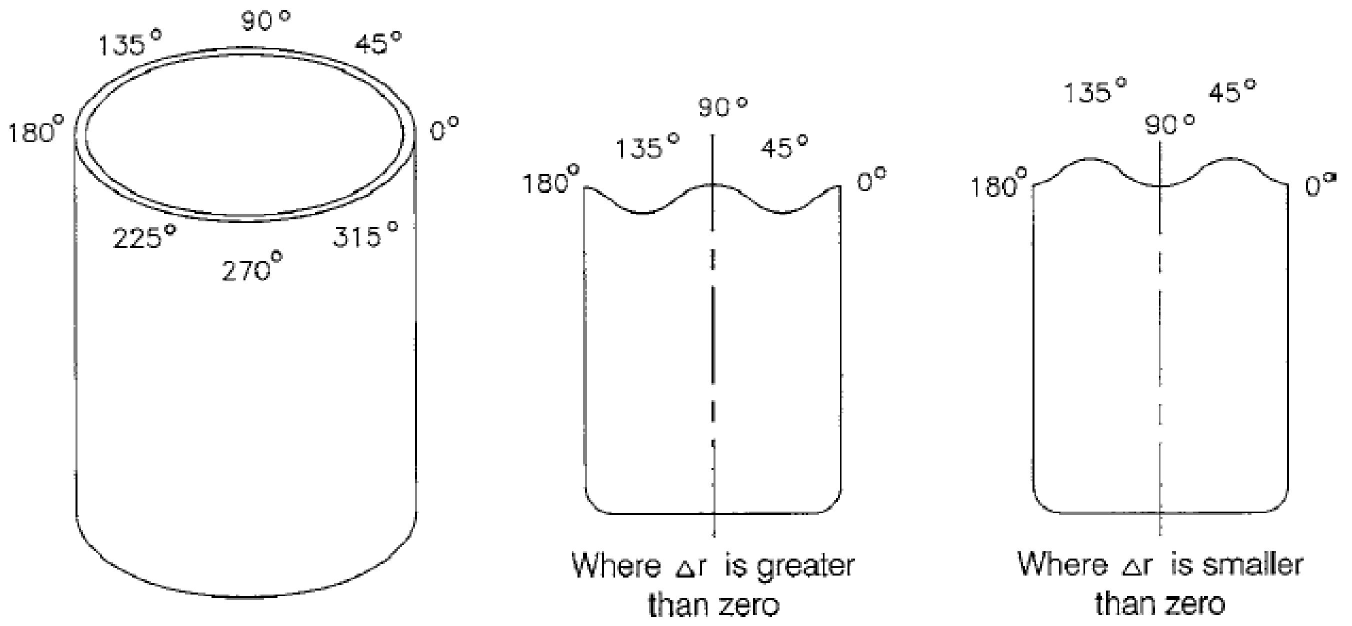




$$\Delta R = ½\ (R_0 - 2R_{45} + R_{90})$$

The Influence of Sheet Metal Properties on Metal Stamping Die Design

Planar Anisotropy



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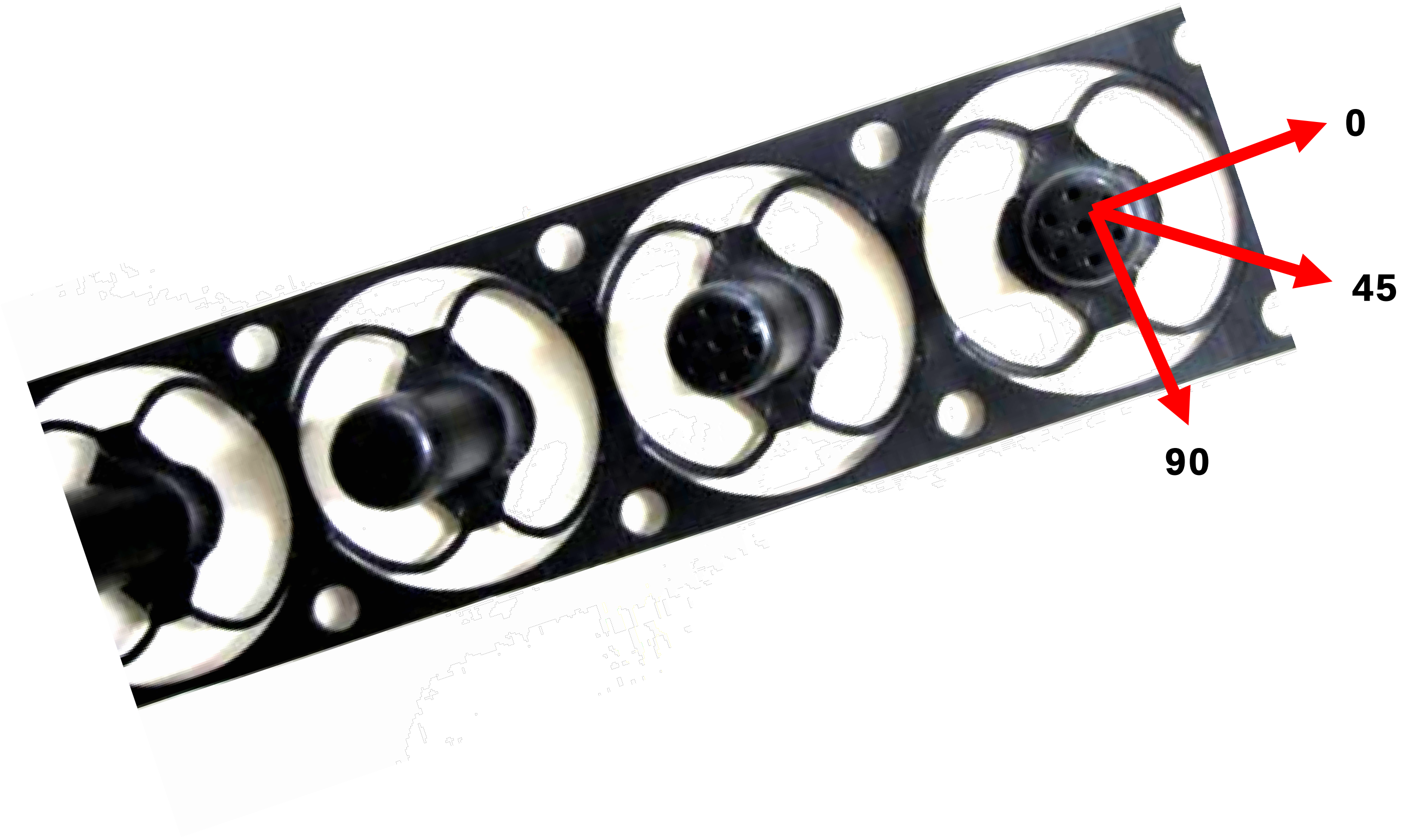
Planar Anisotropy

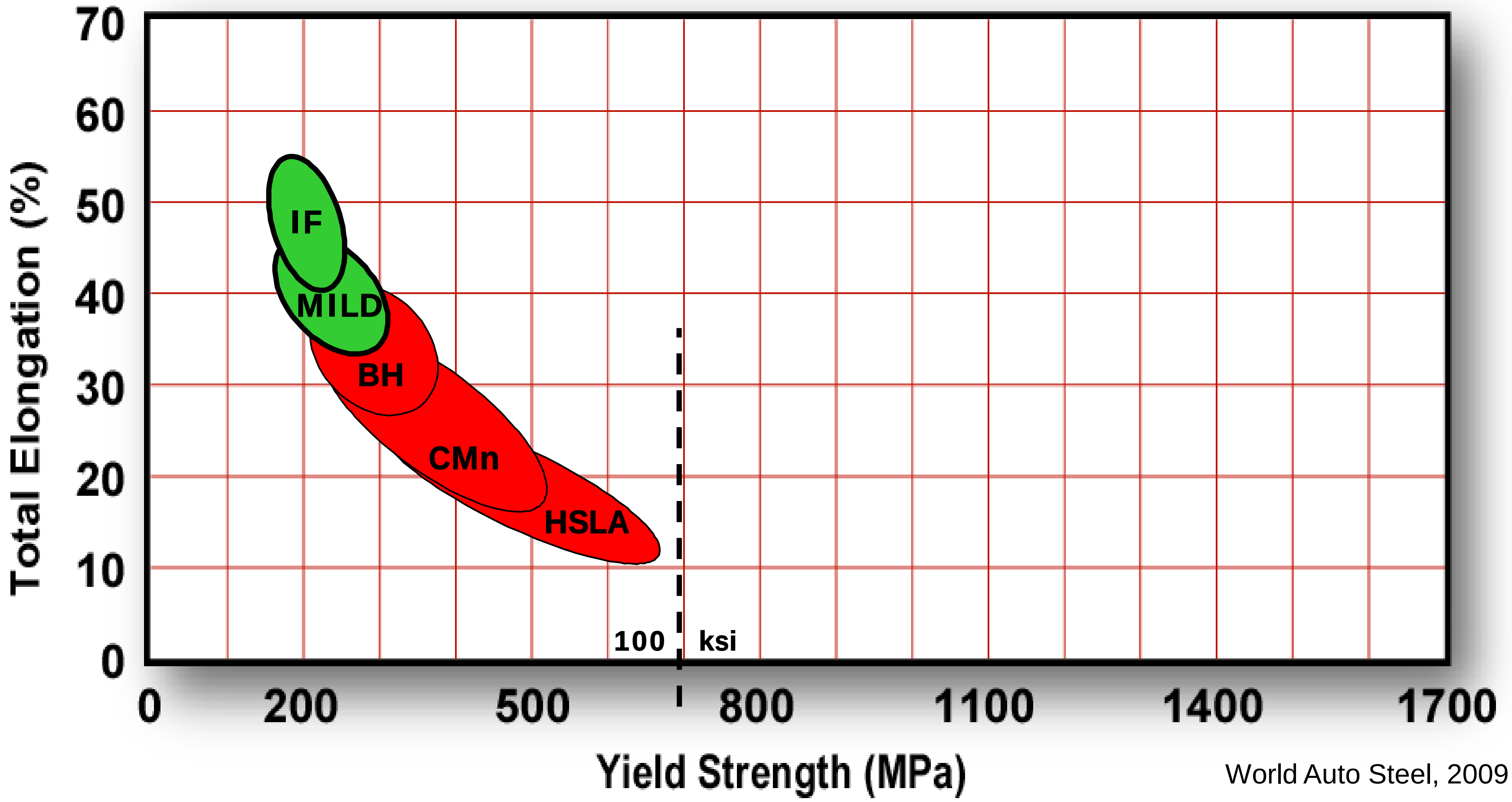


The Influence of Sheet Metal Properties on Metal Stamping Die Design

<u>SUMMARY</u>

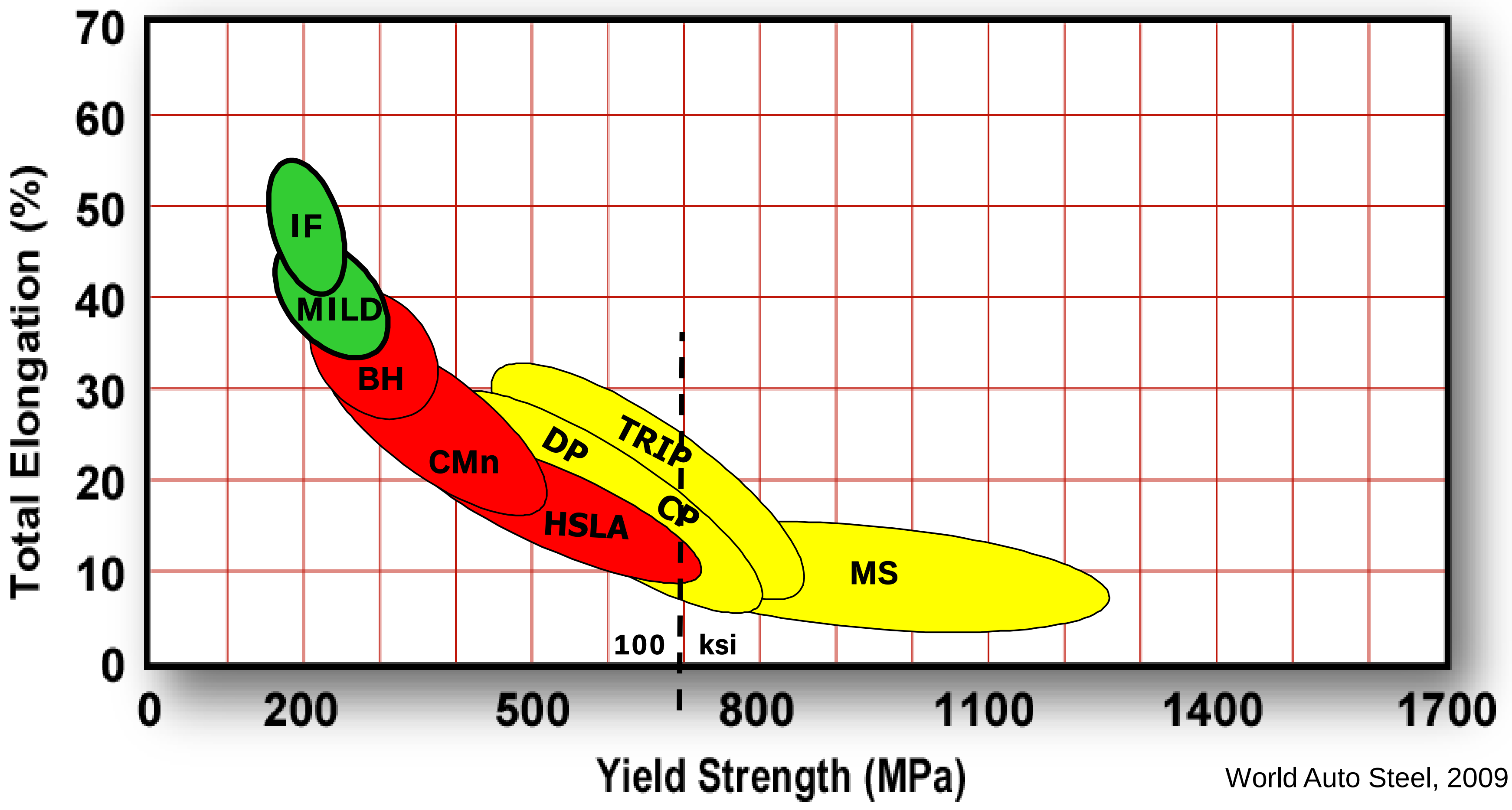
- **<u>BENDING</u>** is related the **total elongation** of a material during uniaxial tension testing
- **<u>STRETCHING</u>** is related to the **n-value**, or work hardening capacity, of the material
- **<u>CUP DRAWING</u>** is related to the **r-value** of a material, or its plastic strain ratio, and it is independent of material strength

The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?



World Auto Steel, 2009

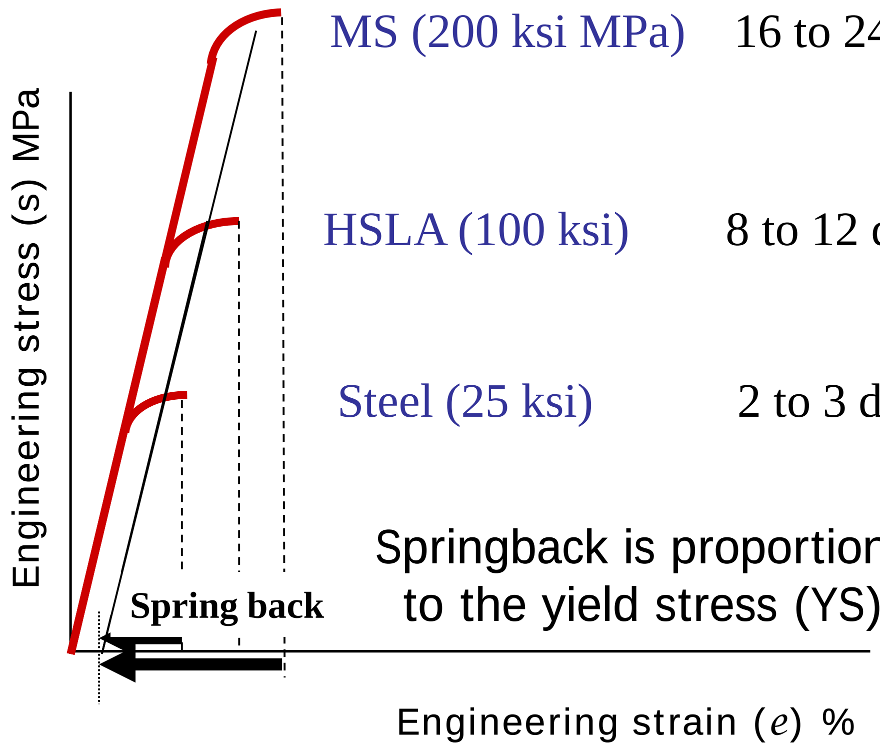
The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?



World Auto Steel, 2009

The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?

Higher forming forces means GREATER springback



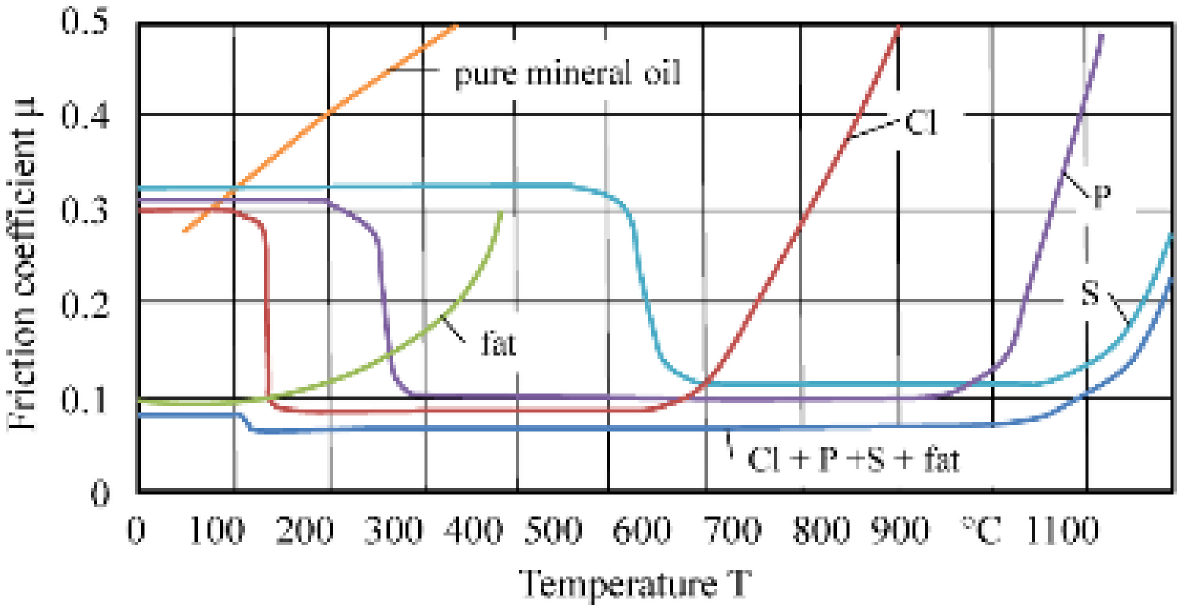
MS (200 ksi MPa)	16 to 24 degrees
HSLA (100 ksi)	8 to 12 degrees
Steel (25 ksi)	2 to 3 degrees

Springback is proportional to the yield stress (YS)

From Stuart Keeler presentation

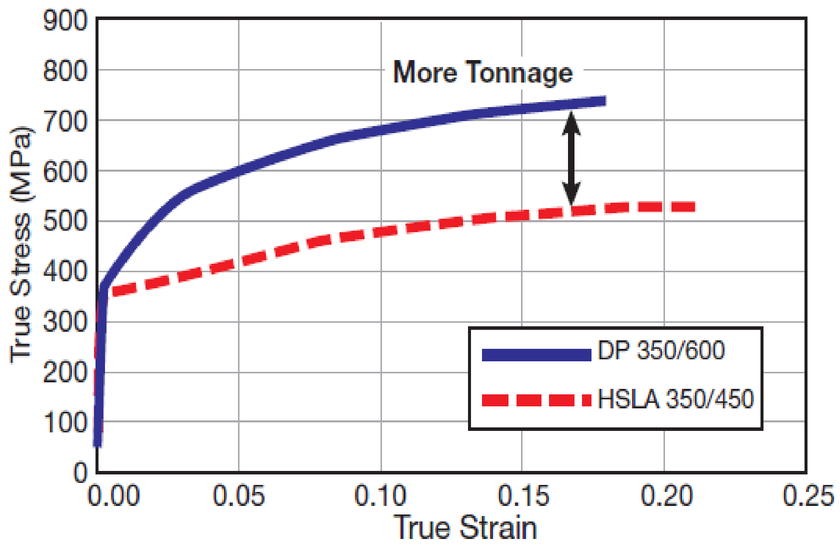
The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?

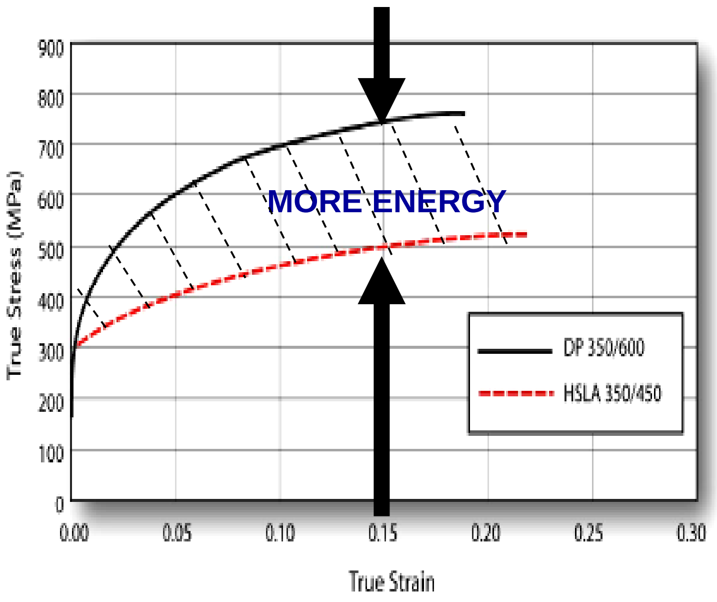
Higher forming forces = higher interface friction = increased die wear



The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?

Higher forming forces means greater press energy requirements





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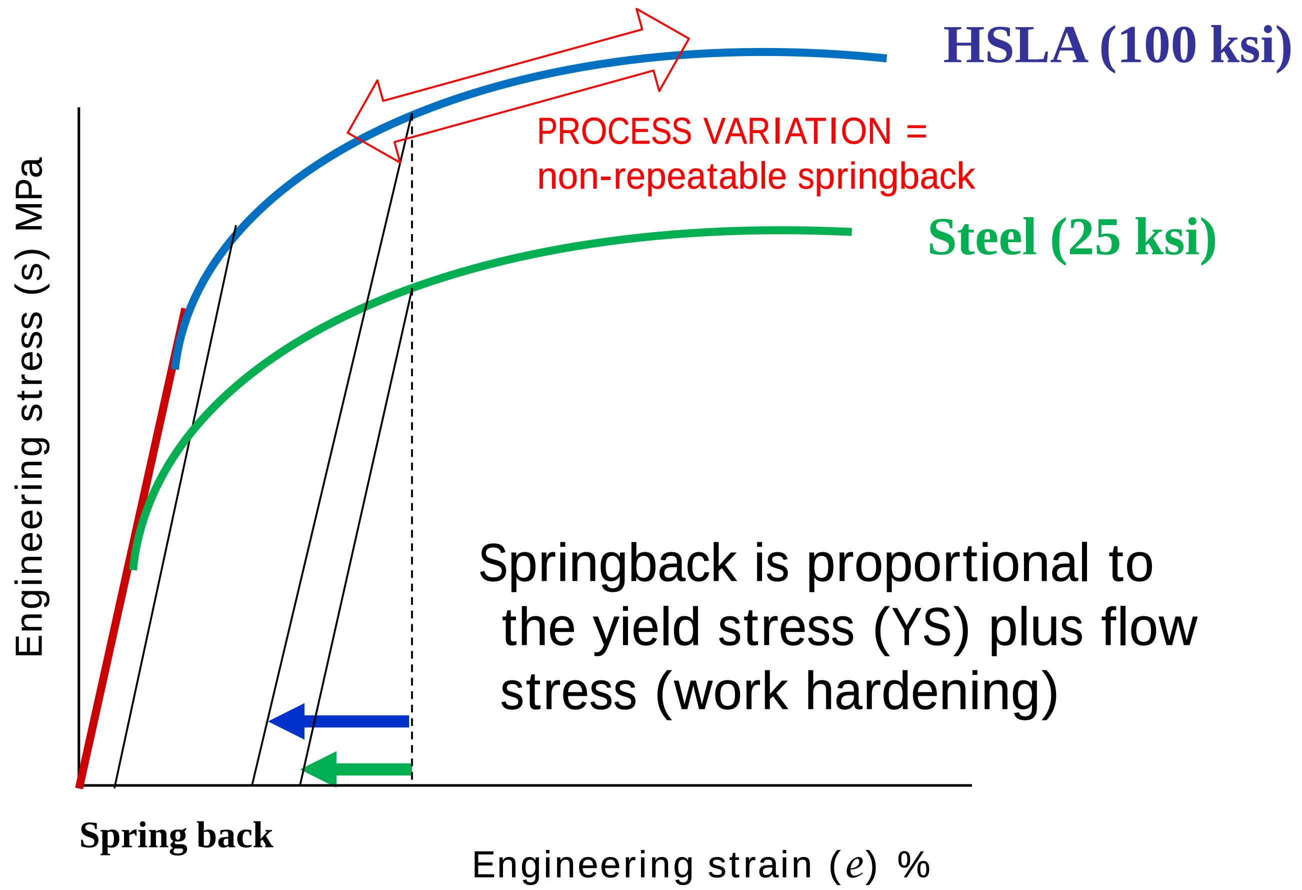
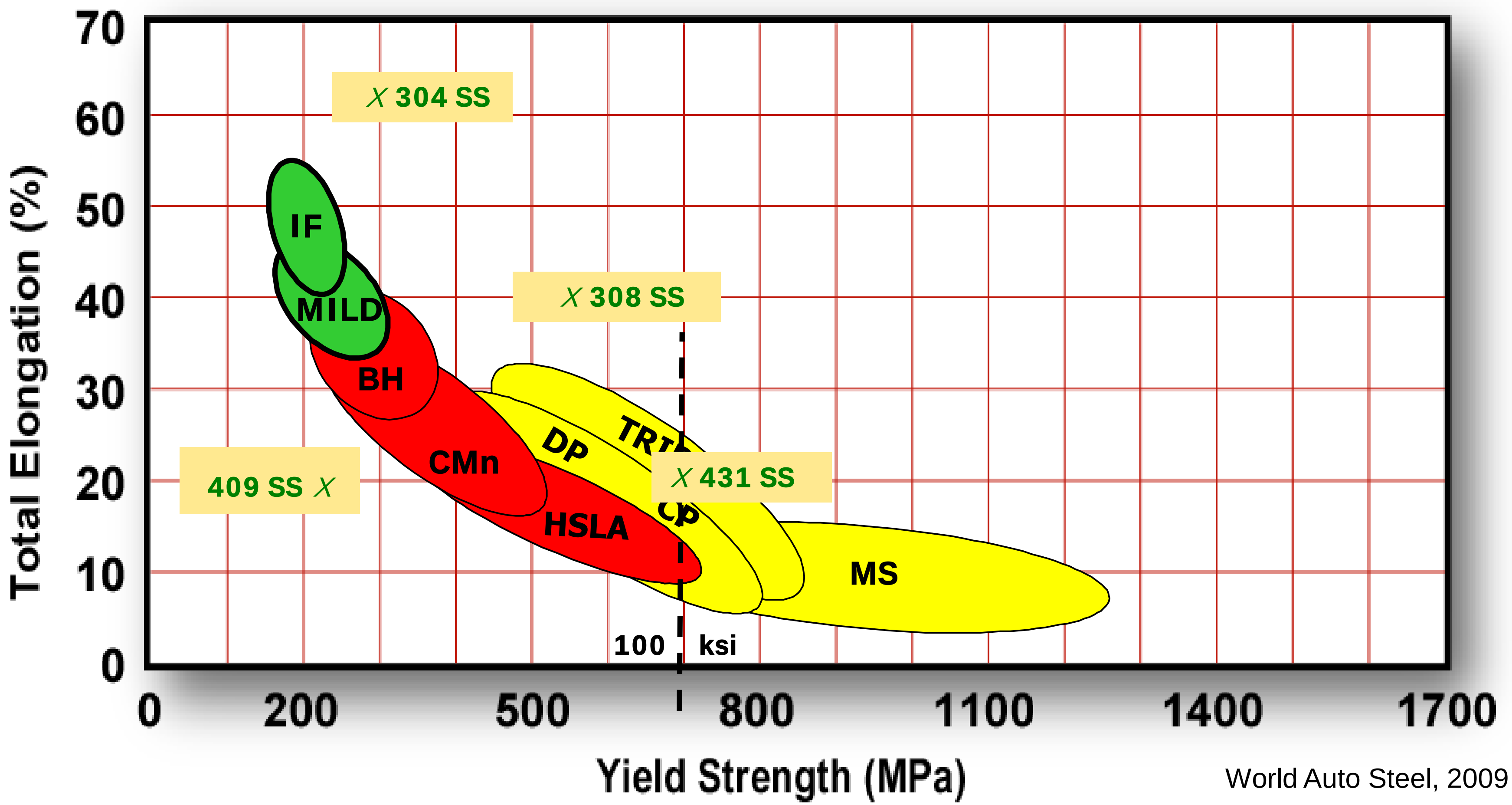


Springback is proportional to the yield stress (YS) plus flow stress (work hardening)

The Influence of Sheet Metal Properties
What Happens When Steels Get Stronger?



World Auto Steel, 2009

The Influence of Stainless Steel's Properties on Metal Stamping Die Design

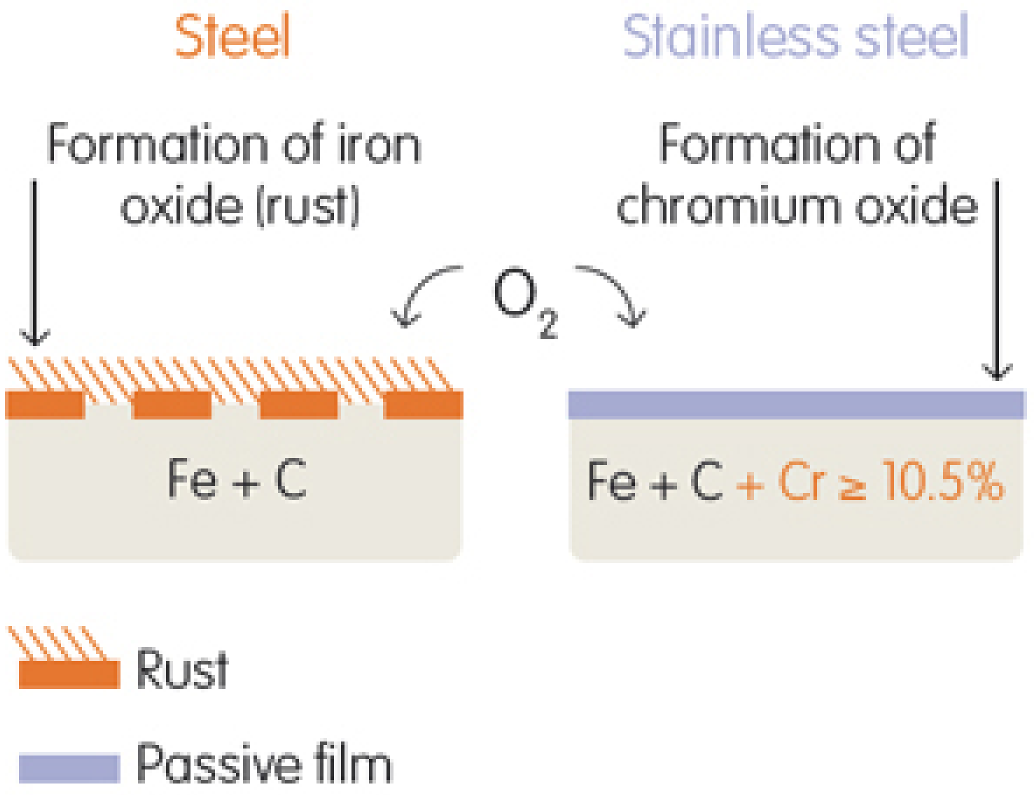
IN GENERAL:

- Stainless steels are iron-based alloys containing more than 10.5% chromium

- The chromium in the steel reacts naturally with oxygen in the air to create a passive chromium-oxide film on the surface of the steel, meaning the metal surface no longer reacts chemically to its surrounding environment

- It is this passive film that stainless steels owe their superior corrosion resistance.

The Influence of Stainless Steel's Properties on Metal Stamping Die Design



The Influence of Stainless Steel's Properties on Metal Stamping Die Design

TOOLING DESIGN CONSIDERATIONS

- Even though the chromium-oxide layer is very thin, it significantly increases the level of friction between the tool and the work piece
- The combination of high forming pressures and surface friction results in significantly higher tool wear rates as compared to low carbon steels
- These higher wear rates increase tool maintenance, downtime and production costs
- As a result, proper processing methods, tool coatings and lubricants must be chosen in order to improve overall tool performance

The Influence of Stainless Steel's Properties on Metal Stamping Die Design

FORMABILITY OF STAINLESS STEEL

- High work hardening capacity $\Rightarrow$ more springback
- Higher strength $\Rightarrow$ greater blank holder force to control metal flow $\Rightarrow$ higher tonnage presses
- Higher press forces $\Rightarrow$ higher temperatures $\Rightarrow$ lubricant break down $\Rightarrow$ **extreme wear conditions**
  - Stainless steel surfaces do not retain lubricants as readily as other metal surfaces

The Influence of Stainless Steel's Properties on Metal Stamping Die Design

WEAR ISSUES

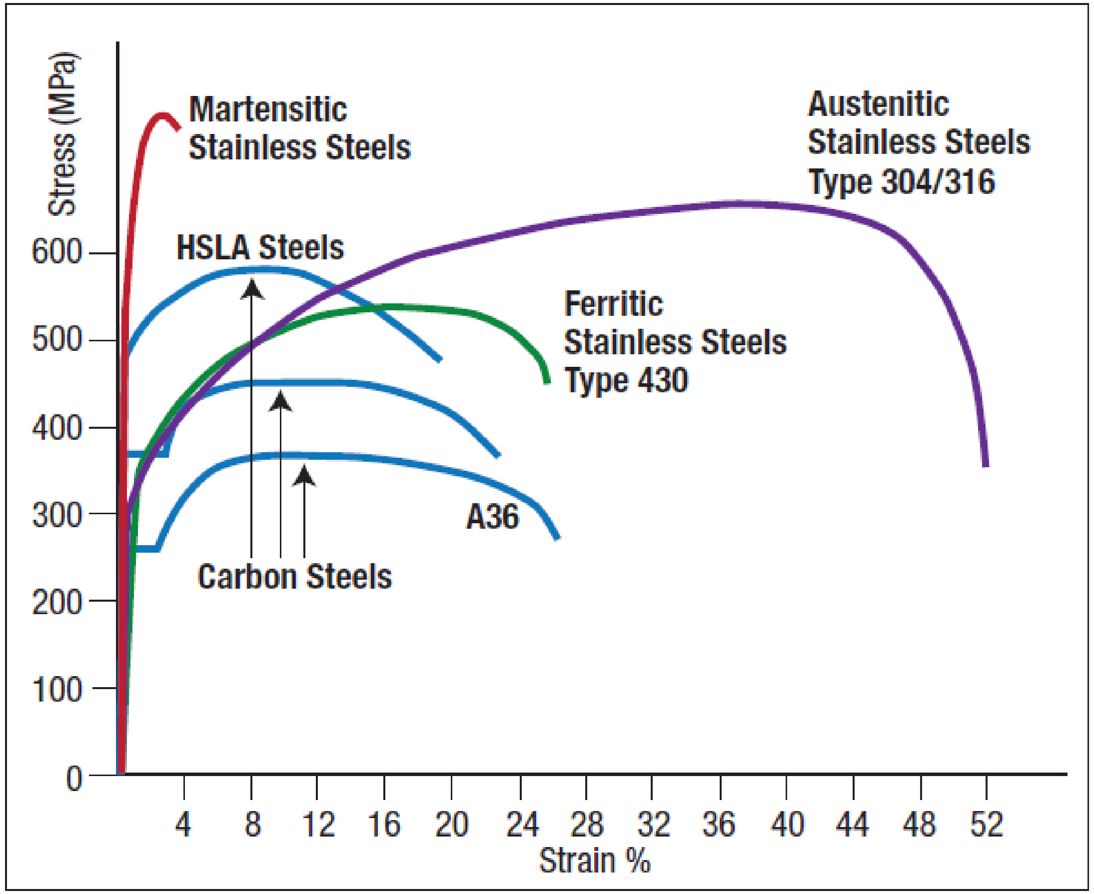
- Dry lubes may be able to provide barrier coating – no sheet contact with the tools = no galling
- Plastic protective coatings on incoming sheet can remain during drawing
  - Aids formability
  - Can be difficult to remove

The Influence of Stainless Steel's Properties on Metal Stamping Die Design

DEEP DRAWING STAINLESS STEEL

- Stainless steels are frequently deep drawn into very complex shapes without the need for intermediate annealing
- Due to the high forming pressures and frictional heat, drawing speeds will be much slower than for plain carbon steel
- Tooling material must be of sufficient hardness and have a highly polished surface
- Even the less formable ferritic grades have outstanding ductility (see illustration on next slide)

The Influence of Stainless Steel's Properties on Metal Stamping Die Design



From MetalForming Magazine, *Tooling By Design*, April 2013, Ulintz

The Influence of Stainless Steel's Properties on Metal Stamping Die Design

DEEP DRAWING STAINLESS STEEL

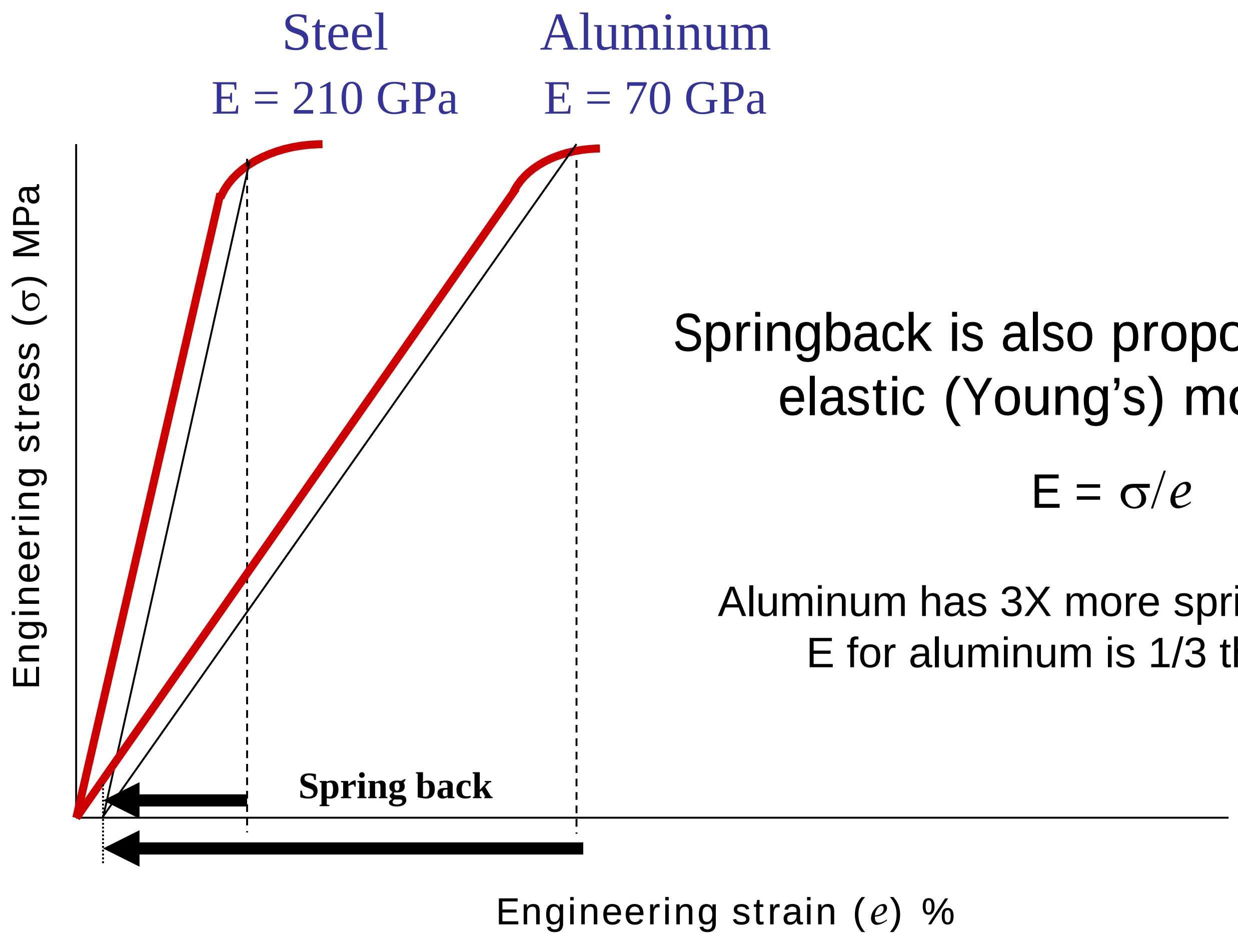
- The required drawing clearances between the draw punch and die cavity wall will be greater for stainless steels compared to plain carbon steels
- Most ferritic alloys require metal thickness plus 10 to 15 percent additional clearance
- Austenitic grades can require metal thickness plus 35 to 40 percent additional clearance
- Hydraulic binder force control may be required for control of metal flow, especially for thin gage material

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

IN GENERAL:

- Aluminum has roughly 60% of the stretching ability of steel
- Aluminum has lower total elongation, 25% vs 40% for steel
- Aluminum has 1/3 the Young's modulus of steel, which increases the likelihood for wrinkling, oil canning, and other surface distortions
- Aluminum has a negative m-value; therefore, it has poor strain distribution characteristics as compared to other materials with positive m-values, like steel

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design



Springback is also proportional to the elastic (Young's) modulus (E)

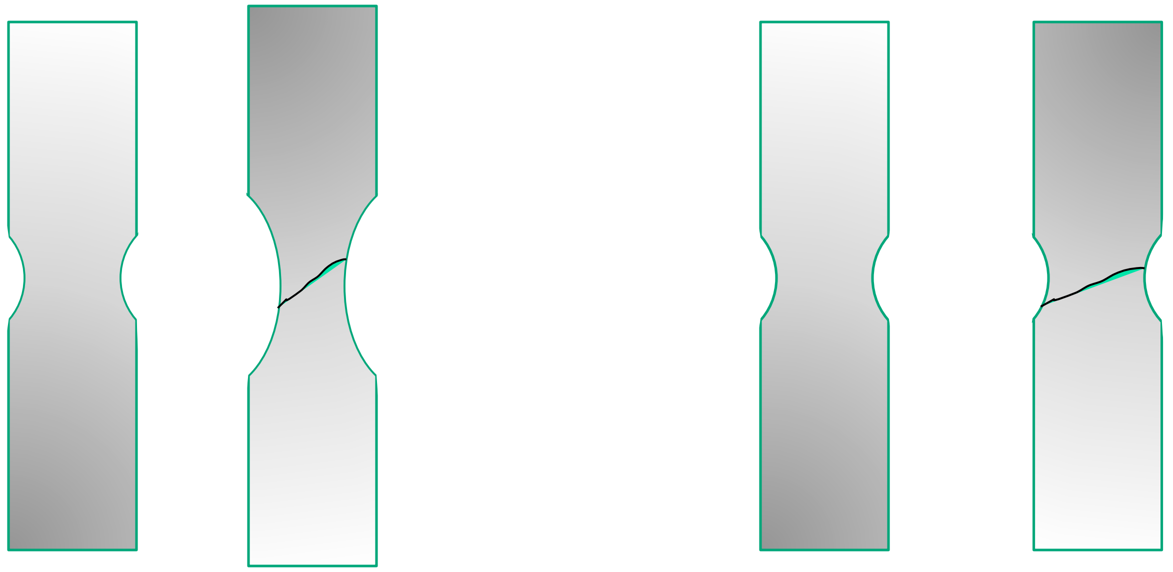
$$E = \sigma / e$$

Aluminum has 3X more springback because E for aluminum is 1/3 that of steel

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

Material with **POSITIVE** m-value

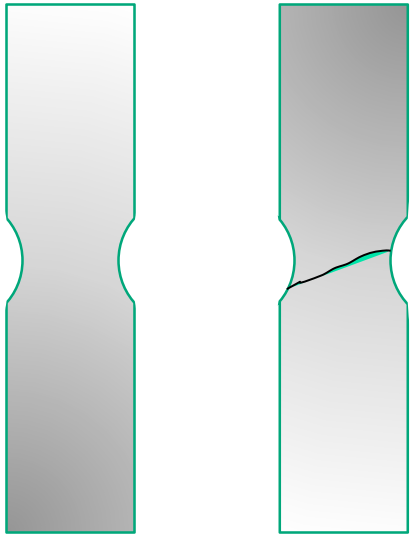
Aluminum



Steel

Material with **NEGATIVE** m-value

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design



Material with **NEGATIVE** m-value

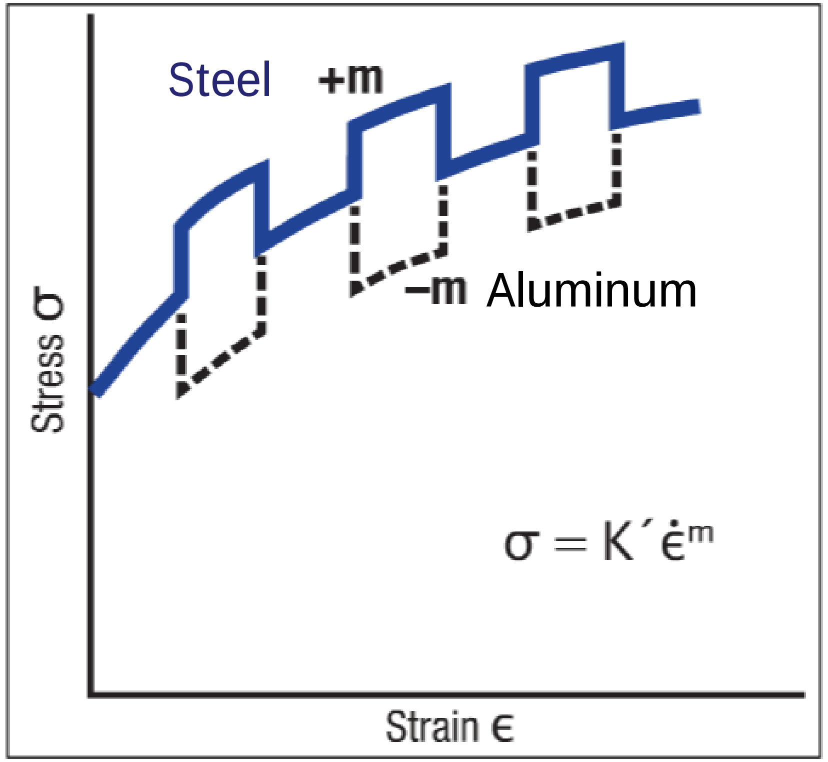


Fig. 1–Changing the speed during a tensile test can provide m-value information.

From *MetalForming* magazine, July 2014, Ulintz & Keeler

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

TOOLING CONSIDERATIONS

- Aluminum has a thin natural layer of aluminum oxide on the surface
- The hard oxide surface layer can be broken during the forming process and rapidly wear the forming tools
- Tool steel selection, heat treatment and surface treatments become very important
- Proper cutting clearance and tool alignment are CRITICAL for reducing slivers in blanking and trimming dies

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

CUTTING CLEARANCE between punch and die depends both on the alloy type and sheet thickness

Alloy, Temper	Yield Strength, KSI	Tensile Strength, KSI	Total Elongation, %	Minimum Bend Radius* (90-deg. bend)	Cutting Clearance per side*, %t
3003-O	5	14	25	0	5%
3003-H14	17	20	5	0	6%
3003- H16	21	24	4	1t	7%
5052-O	9.5	25	19	0	6.5%
5052-H32	23	31	7	1t	7%
6061-O	12 max	22 max	16	0	5.5%
6061-T4	16	30	16	1t	6%
6061-T-6	35	42	10	1.5t	7%

From *MetalForming* magazine, *Tooling By Design*, June 2014, Ulintz

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

FORMABILITY OF ALUMINUM - in terms of total elongation - varies between the alloy types and tempers within a given alloy

Alloy, Temper	Yield Strength, KSI	Tensile Strength, KSI	Total Elongation, %
3003-0	5	14	25
3003-H14	17	20	5
3003- H16	21	24	4
5052-0	9.5	25	19
5052-H32	23	31	7
6061-0	12 max	22 max	16
6061-T4	16	30	16
6061-T-6	35	42	10

From *MetalForming* magazine, *Tooling By Design*, June 2014, Ulintz

The Influence of Aluminum Alloy Properties on Metal Stamping Die Design

DEEP DRAWING ALUMINUM

Irregular-shaped product geometries often benefit from the use of addendum to improve material flow

Die designers add addendum features beyond the product trim line to assist material flow by balancing cross-sectional lengths of line and providing a constant depth of draw

The ideal aluminum stamping design stretches evenly and distributes strains uniformly when deformed

The Influence of Sheet Metal Thickness on Metal Stamping Die Design

BENDING ALUMINUM requires special attention

- For most metals, the minimum bending radius relative to sheet thickness is approximately constant, primarily because ductility (total elongation) tends to be the limiting factor for minimum bend radii.

- This is not the case with aluminum alloys. In general, the ratio of bend radius to sheet thickness will need increase with sheet thickness

Alloy, Temper	0.016 in. thick	0.032 in. thick	0.064 in. thick	0.125 in. thick
3003-H16	0.5t	1t	1t	1.5t
5052-H34	0t	1t	1.5t	2t
6061-T6	1t	1t	1.5t	2.5t

From *MetalForming* magazine, *Tooling By Design*, June 2014, Ulintz

The Influence of Sheet Metal Thickness on Metal Stamping Die Design

Due to the higher stresses required to penetrate higher strength materials, additional cutting clearances are required:

Scaling Factor— Engineered Die Clearance

Thickness Scaling Factor	< 0.060" (1.5mm)	> 0.060" (1.5mm)	> 0.120" (3.0mm)
HSS	1.00	1.20	1.40
AHSS	1.00	1.20	1.40
UHSS	1.00	1.30	1.40

Source: Dayton Progress

The Influence of Sheet Metal Thickness on Metal Stamping Die Design