Forming of High Strength Steel Sheets

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Cold Stamping of High Strength Steel Sheets

1. High strength steel sheet
2. Springback in bending
3. Stretch flangeability
4. Fracture
5. Galling and seizure
6. Wrinkling
7. Shearing
8. Tailored blank
9. Plastic joining

Forming of lightweight automobile parts

Reduction in 100 kg weight: 1km/*l*

Material

- High strength steel sheet (7.8)
- Aluminium (2.7), Magnesium (1.8), Titanum (4.5)

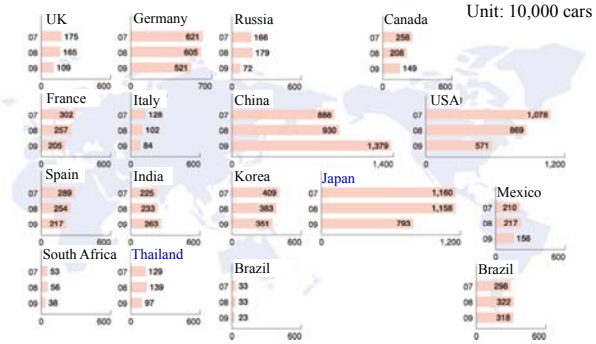
Part

- Hollow parts
- One piece

Simulation

- Finite element method

Production of automobiles in countries



Environmentally friendly automobiles: Hybrid

Toyota Prius

Honda Fit-Jazz

Toyota Prius PHV

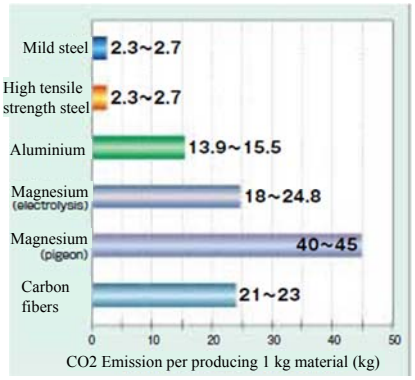
Environmentally friendly automobiles: Electric

Nissan Leaf

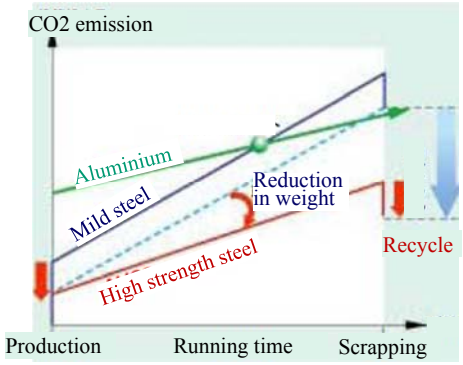
Mitsubishi i-MiEV

Tesla Roadster

CO2 emission for producing automobile materials



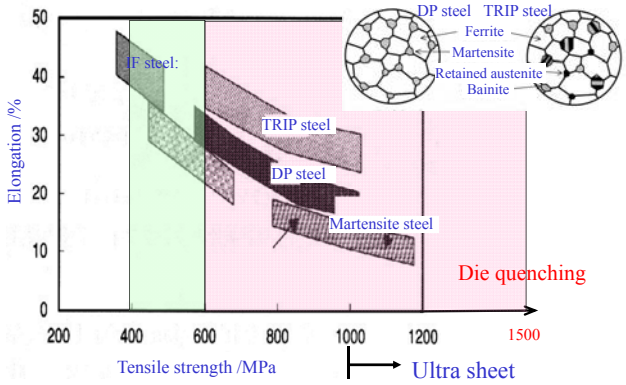
自動車使用におけるCO_2排出量



Specific strength for various sheet metals

Sheet	Tensile strength	Specific gravity	Strength-to-specific gravity ratio
Ultra high strength steel	980 - 1470MPa	7.8	126 - 188MPa
High strength steel	490-790MPa	7.8	63-101MPa
Mild steel SPCC	340MPa	7.8	44MPa
Aluminium alloy A6061(T6)	310MPa	2.7	115MPa

High strength steel sheets

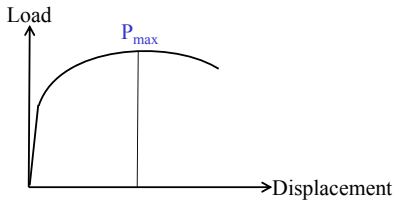


High strength steel sheet

High Strength Steel Sheet, HSS, AHSS, Ultra HSS

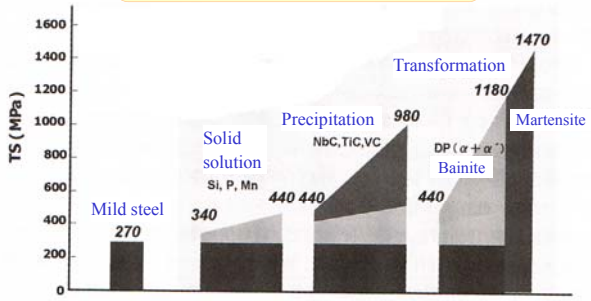
Tensile strength: 440, 490, 590 780, 1180 MPa

P_{max}/A_0

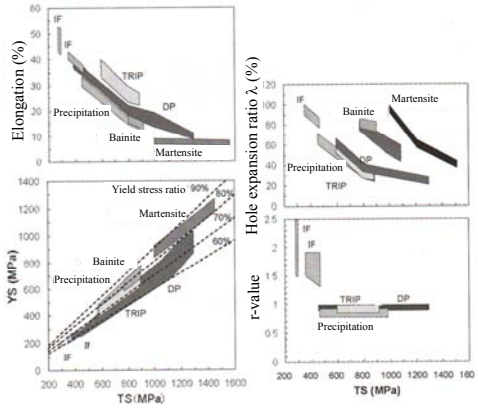


A_0: initial cross-sectional area

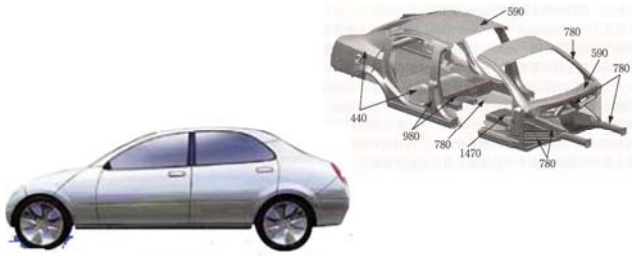
Mechanism of strengthening of high strength steel sheet



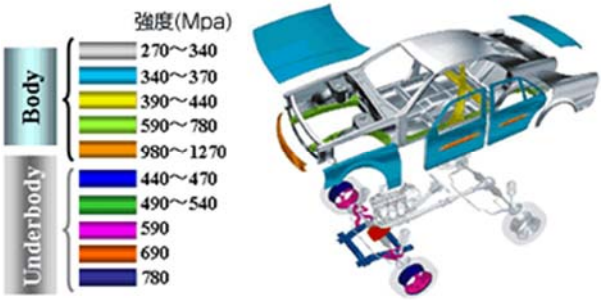
Properties of high strength steel sheets



ULSAB-AVC (Ultra Light Steel Auto Body - Advanced Vehicle Concept)

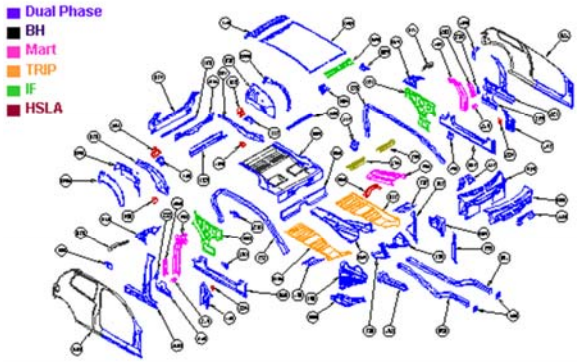


Application of high strength steel sheets to automobile body

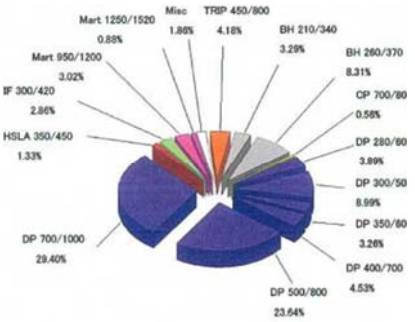


36% of total weight

Used steel sheets



Used steel sheets

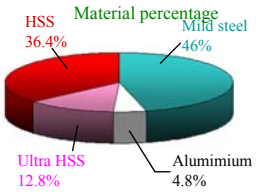


Results of ULSAB-AVC

		C-Class 1500CC		PNGV-Class 2500CC		
		Gasoline	Diesel	Gasoline	Diesel	
Fuel consumption	燃費(l/100km)※	4.4	3.2	4.5	3.4	
	CO2 g/km	105	86	108	92	≦140g/km
	燃費(km/l)	22.5	31.0	22.1	29.0	
Weight	車両重量(kg)	933(−19%)	966	998(−32%)	1031	
	ベンチマーク	1147		1470		
	ボデー重量(kg)	202	202	218	218	
	ベンチマーク	243		263		
Collision safety	米国前面衝突	4-5★		5★		
	米国側面衝突	5★		5★		
	欧州ポール側突	5★		5★		
Production cost		$9190	$9690	$9538	$10238	

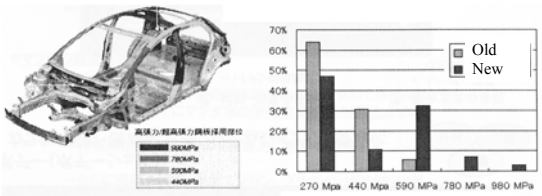
Application of high strength steel sheets to automobile body

Subaru Legacy



Toyota Crown,
45% of body panels

Mazda, Demio



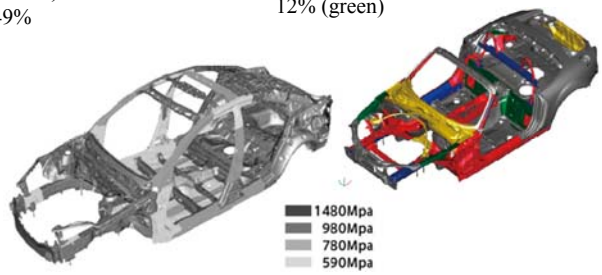
High strength steel sheets: from 40% to 60%

8% reduction in weight

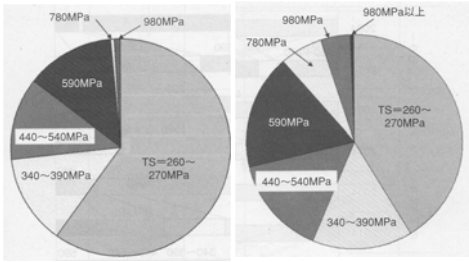
Mazda, Atenza, Roadstar

Mazda, Atenza: from 42% to 49%

Mazda, Roadstar, 1500MPa: 12% (green)

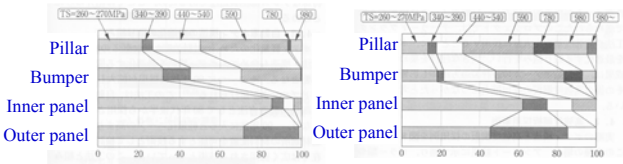


Chang in percentage of use of HSS



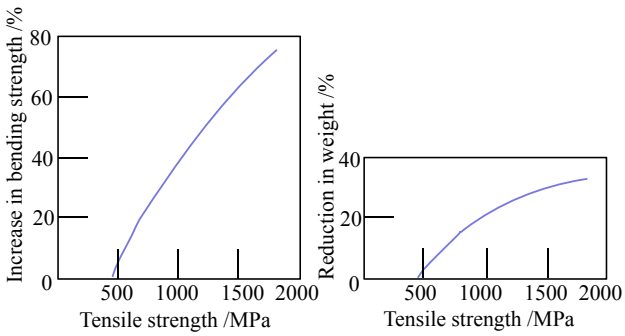
(a) 2004 (b) 2014

Use of HSS in automobile body panels



(a) 2004 (b) 2014

Increase in strength and reduction in weight



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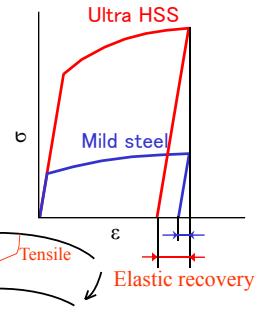
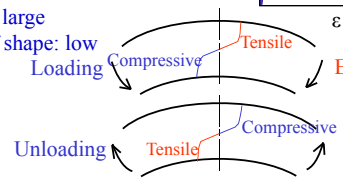
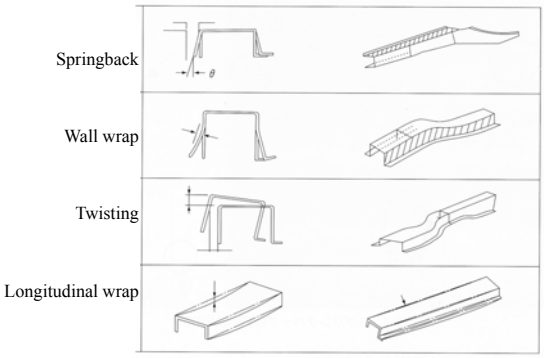
Springback in bending



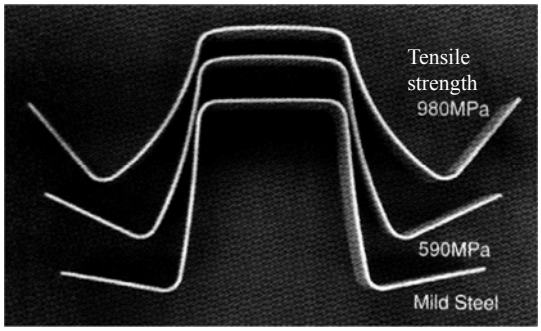
Springback: large
Accuracy of shape: low



Deterioration in shape accuracy of formed parts



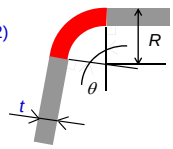
Springback in hat-shaped bending of HSS



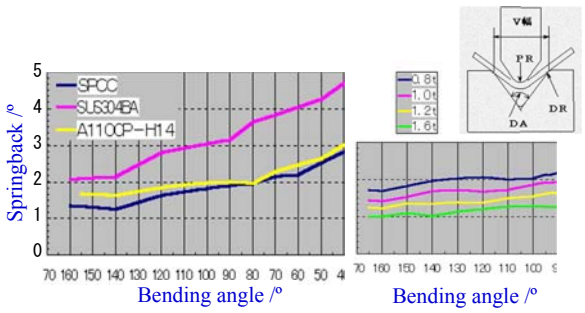
Springback in bending

$$\Delta\theta = \frac{M}{E\,I}\theta R \approx \frac{3\sigma\,\theta R}{E\,t}$$

$\Delta\theta$: Springback
M : Bending moment ($bt^2\sigma/4$)
I : Geometrical moment of inertia ($bh^3/12$)
σ : Flow stress
E : Young's modulus
t : Thickness
θ : Bend angle
R : Radius

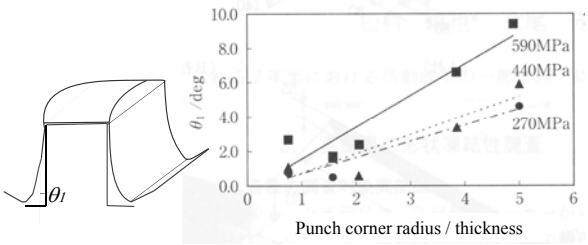


Effects of material and thickness in V-shaped bending

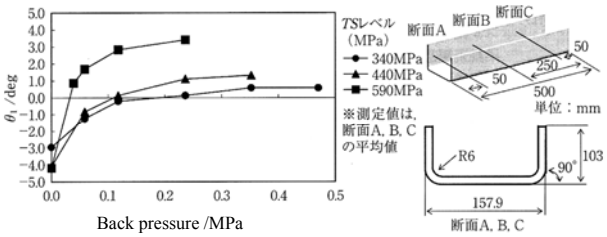


(a) Material (b) Thickness

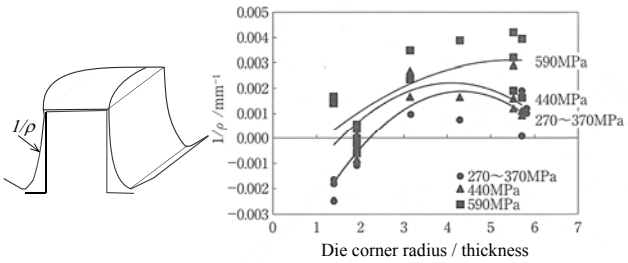
Effect of strength on springback in hat-shaped bending



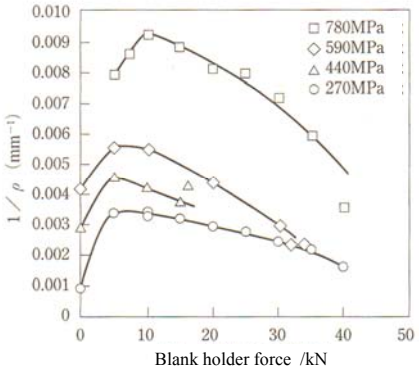
Effect of back pressure on springback in U-shaped bending



Effect of strength on wrap in hat-shaped bending

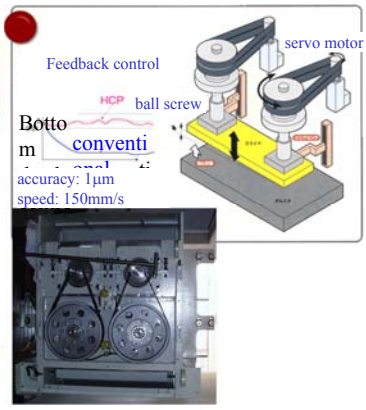


Effect of blank holder force on wrap in hat-shaped bending

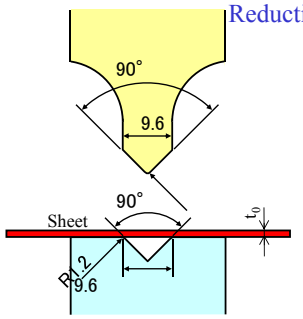


800kN CNC Servo Press

Direct driving type

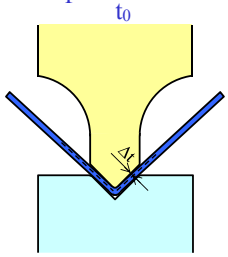


Reduction in springback in V-shaped bending

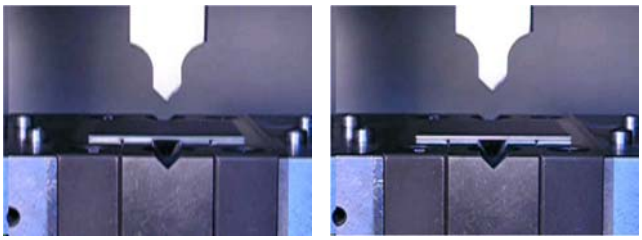


Reduction in thickness in bottoming

$$f = \frac{\Delta t}{t_0}$$



Deformation behaviour in V-shaped bending

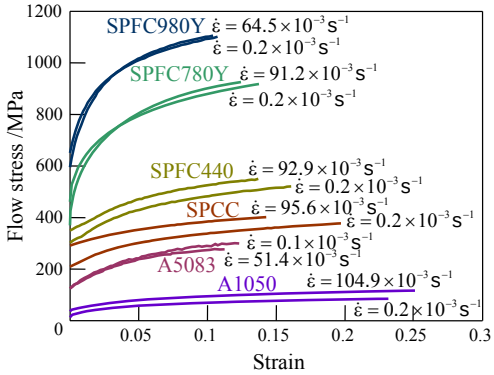


(a) SPCC (b) SPFC980Y

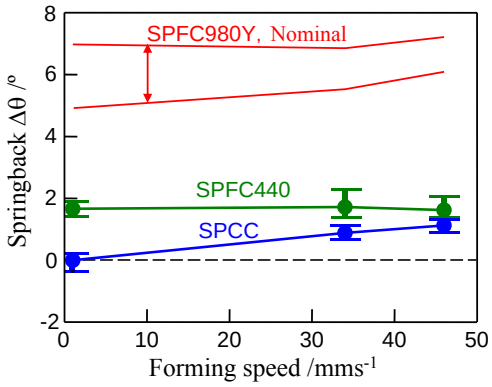
v=24mm/s, f=0%, T=0.5s
3 times slower

Flow stress curve of sheets at room temperature

Large springback

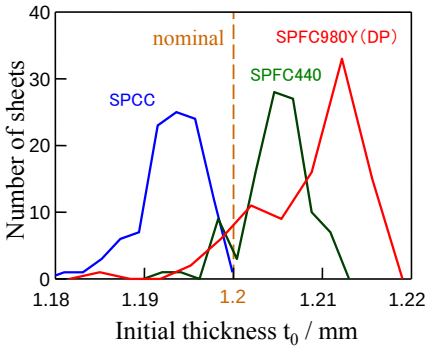


Relationship between springback and forming speed in V-shaped bending (f=0%, T=0s)

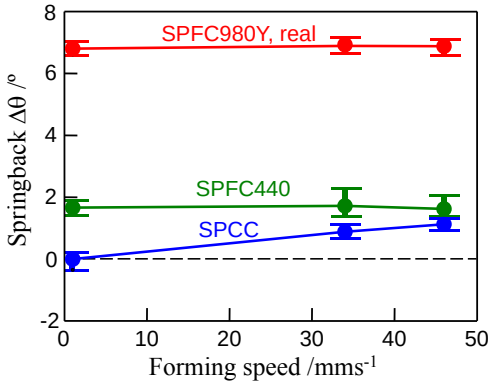


Scatter of initial thickness of sheets

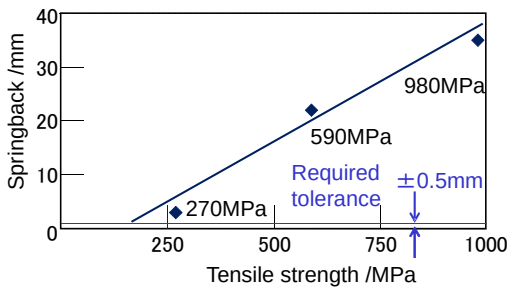
Sheet	SPFC980Y (DP), SPFC440 (IF), SPCC
Nominal thickness	1.2mm



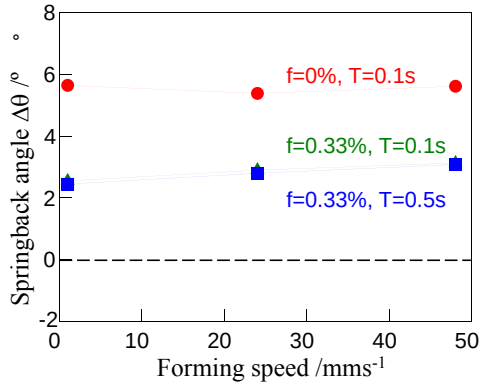
Relationship between springback and forming speed in V-shaped bending (f=0%, T=0s)



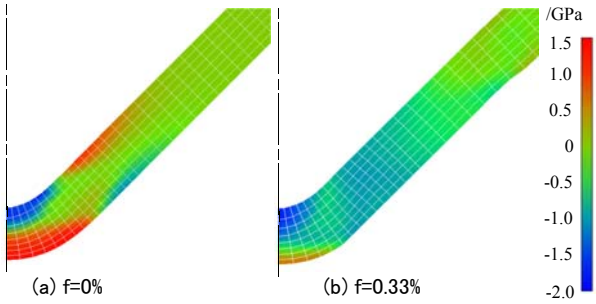
Relationship between springback and tensile strength



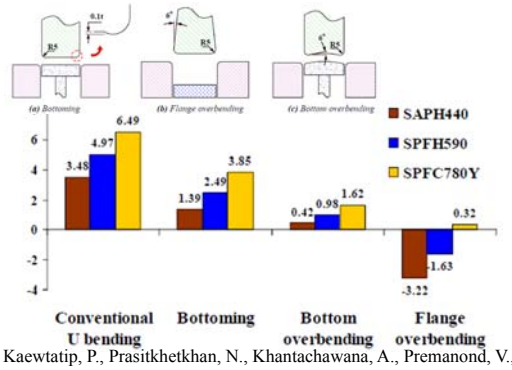
Effects of bottoming and holding time at bottom dead centre for SPFC980Y



Distribution of stress in width direction just after unloading for finishing reduction in thickness

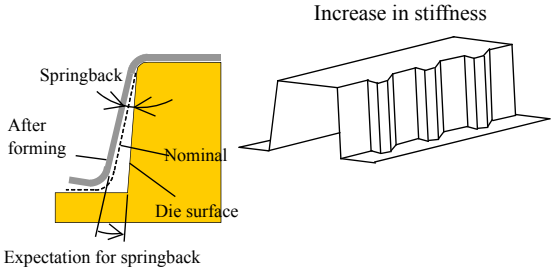


Effect of bottoming



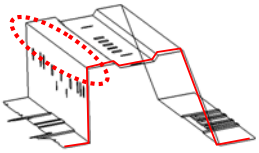
Kaewtatip, P., Prasitkhetkhan, N., Khantachawana, A., Premanond, V., Hato, R., Sresomreong, B., Koga, N., Proc. 9th ICTP, (2008).

Prevention of springback by beads in side wall



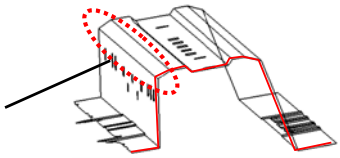
Prevention of springback by chamfering

【Old shape】

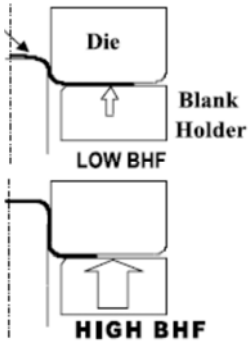


【New shape】

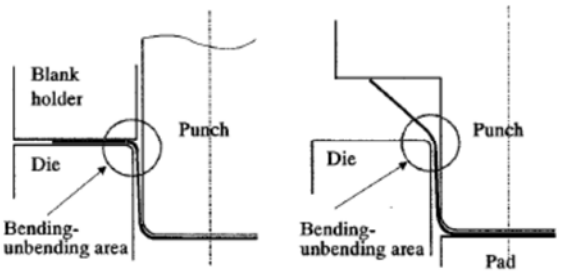
Chamfer shape



Prevention of springback by control of blank holder force

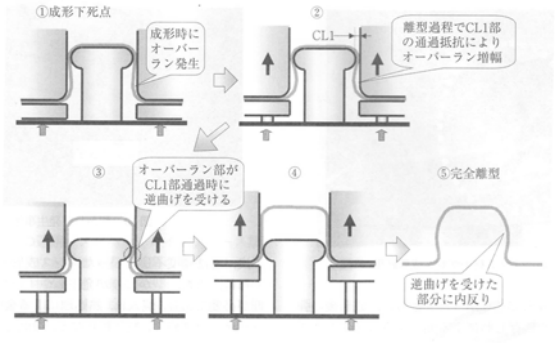


Prevention of springback by crash forming



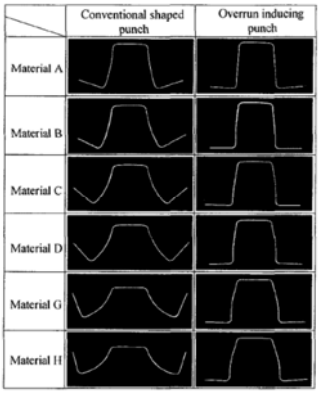
(a) Draw bending (b) Crash forming without blank holder

Prevention of springback by overrun inducing punch

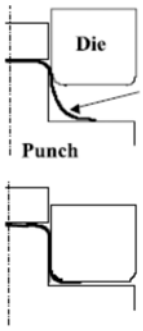


Prevention of springback by overrun inducing punch

Tensile strength /MPa



Prevention of springback by crash forming



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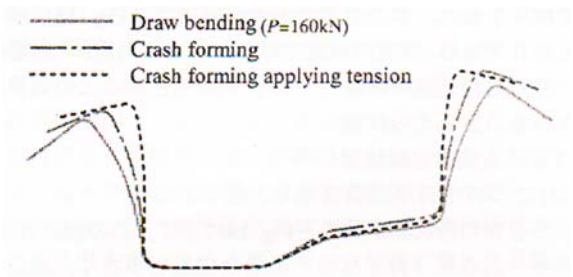
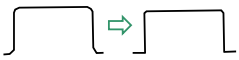
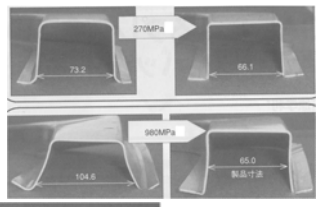


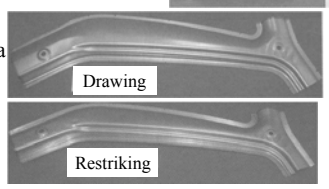
Prevention of springback and twisting by restriking



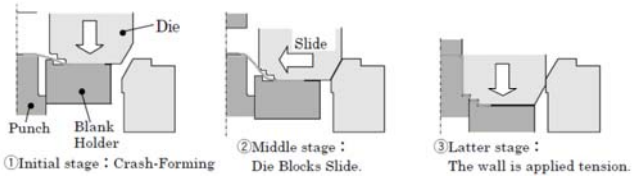
(a) Drawing (b) Restriking



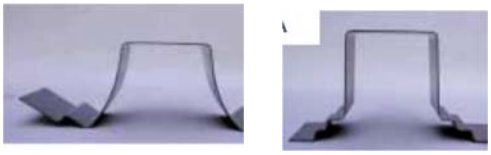
980MPa



Prevention of springback by slide locking



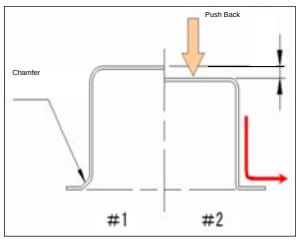
780MPa

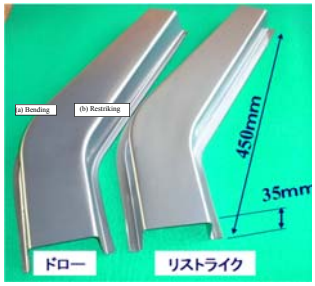


(a) Drawing (b) Slide locking

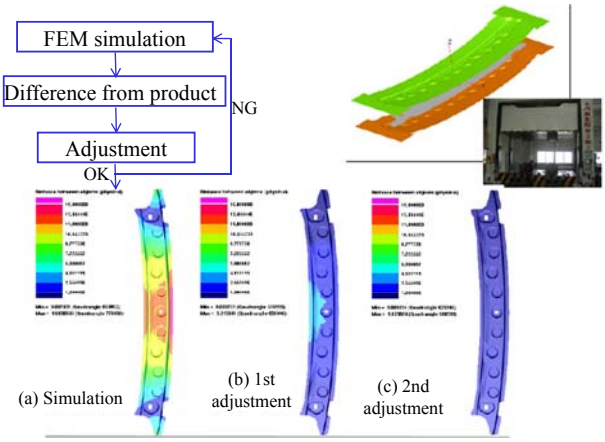
Prevention of springback and twisting by chamfered bending and push-back forming

590MPa, 1.0 mm



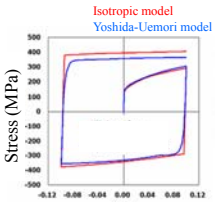


Adjustment of die shape by finite element simulation

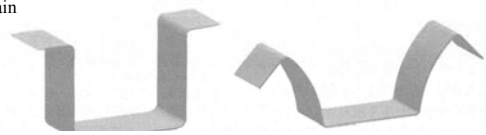


(a) Simulation (b) 1st adjustment (c) 2nd adjustment

Effect of constitutive equations on calculated springback by finite element simulation



(a) Experimental result (980 MPa)

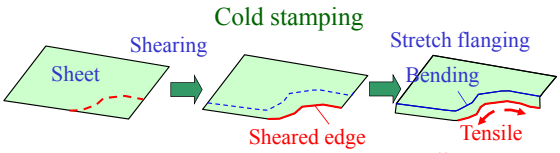


(b) Isotropic model (c) Yoshida-Uemori model

Cold Stamping of High Strength Steel Sheets

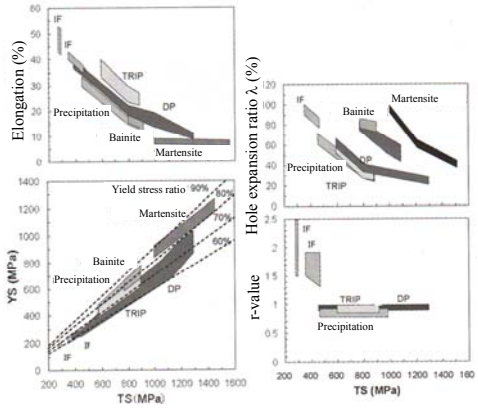
1. High strength steel sheet
2. Springback in bending
3. Stretch flangeability
4. Fracture
5. Galling and seizure
6. Wrinkling
7. Shearing
8. Tailored blank
9. Plastic joining

Fracture in stretch flanging of high strength steel sheets



780MPa high strength steel formed product

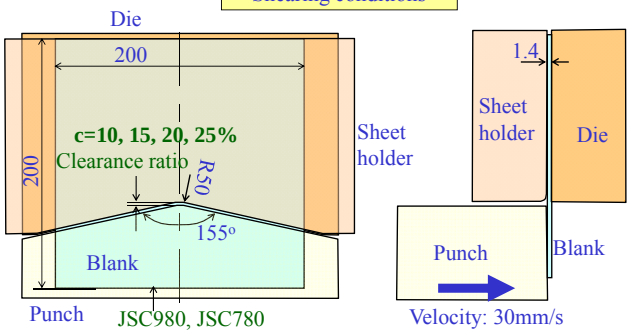
Properties of high strength steel sheets



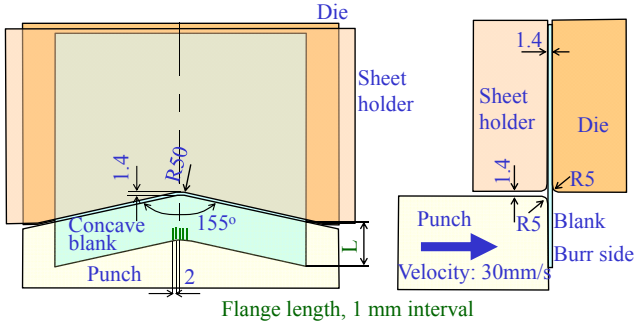
Steel sheets used for punching and stretch flanging

Sheet	Thickness [mm]	Yield stress [MPa]	Tensile strength [MPa]	Elongation [%]	n-value
JSC980Y	1.41	620	1027	18.7	0.12
JSC780Y	1.41	558	823	19.0	0.12
JSC590R	1.40	446	600	26.2	0.14
JSC440W	1.41	320	455	33.8	0.18
JSC390W	1.39	283	389	35.8	0.18
JSC270C	1.39	223	333	41.2	0.19

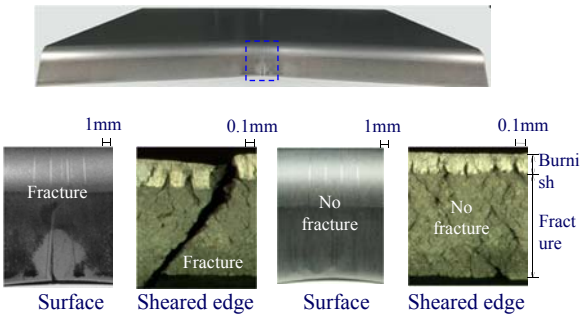
Shearing conditions



Stretch flanging conditions

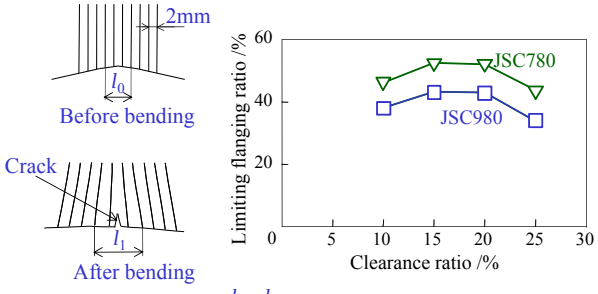


Effect of clearance ratio of occurrence of fracture (JSC980Y, L=15mm)



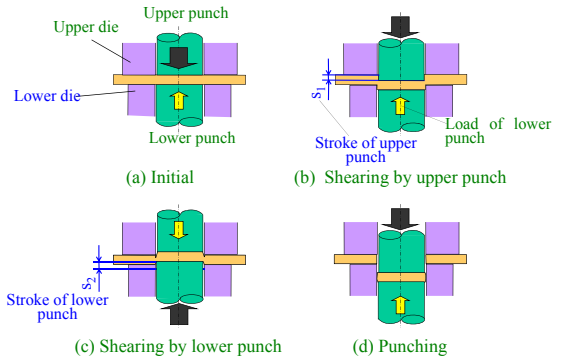
(a) c =20% (b) c =15%

Relationship between limiting flanging ratio and clearance ratio

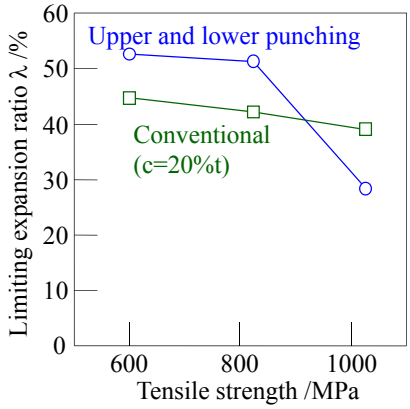


Limiting flanging ratio: $\frac{l_1 - l_0}{l_0}$

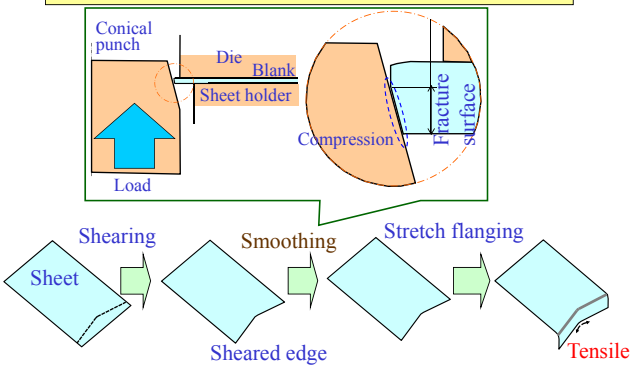
Improvement of stretch flangeability by upper and lower punching



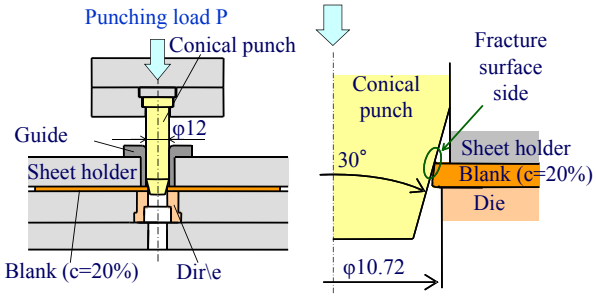
Relationship between limiting expansion ratio and tensile strength



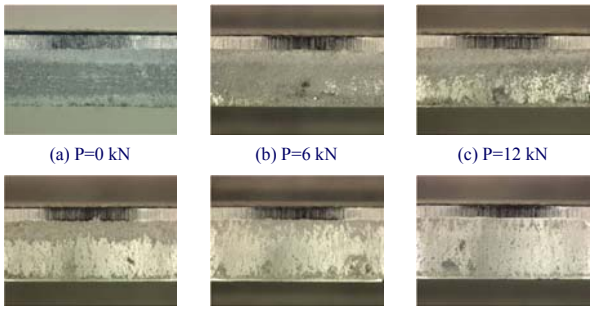
Smoothing of fracture surface on sheared edge with conical punch



Smoothing of fracture surface on sheared edge with conical punch in punching



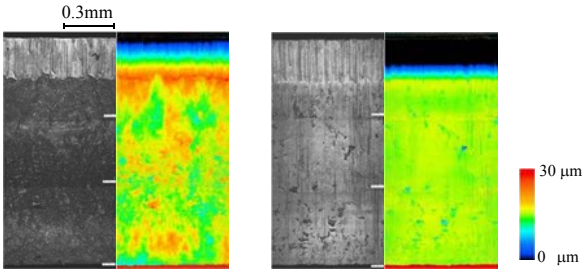
Smoothing of fracture surface on sheared edge of punched sheet (JSC980Y)



(a) P=0 kN (b) P=6 kN (c) P=12 kN

(d) P=16 kN (e) P=20 kN (f) P=22 kN

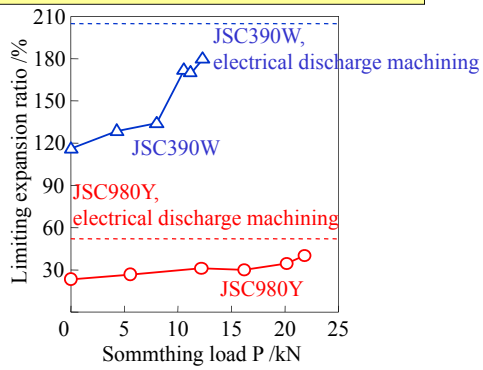
Smoothed sheared edge (JSC980Y)



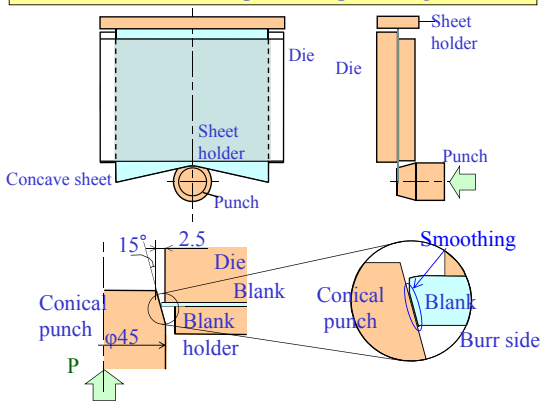
(i) Surface (ii) Height
(a) P=0kN
(Punched edge)

(i) Surface (ii) Height
(b) P=22kN

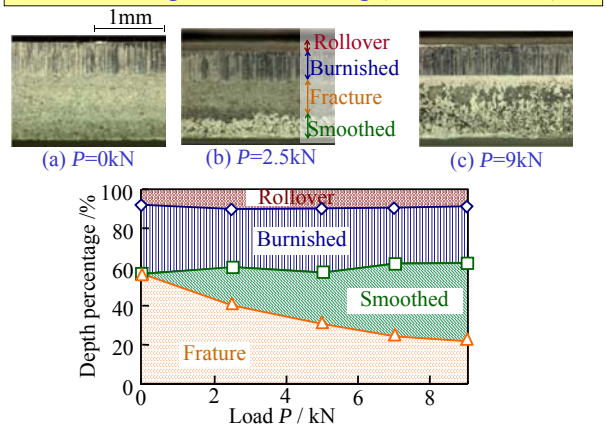
Improvement of limiting expansion ratio by smoothing (JSC980Y)



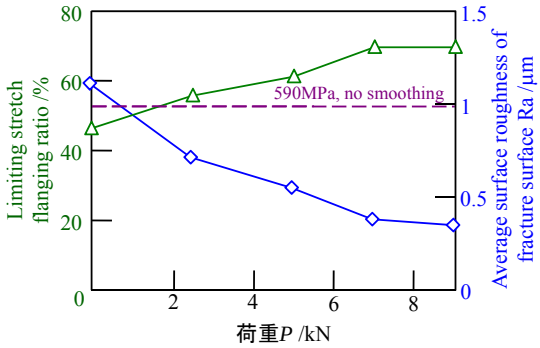
Smoothing of fracture surface on sheared edge with conical punch in punching



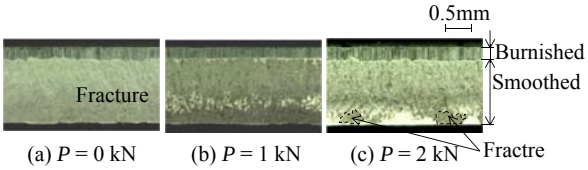
Sheared edge after smoothing (JSC780, *c*=20%)



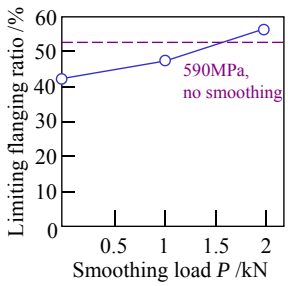
Improvement of limiting stretch flanging ratio (JSC780, c=20%)



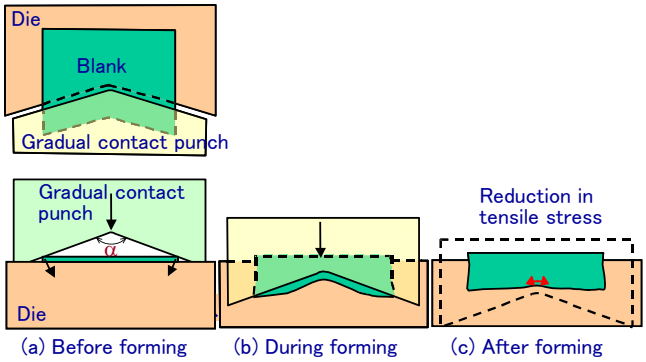
Sheared edge before and after smoothing (JSC980Y, *c*=15%)



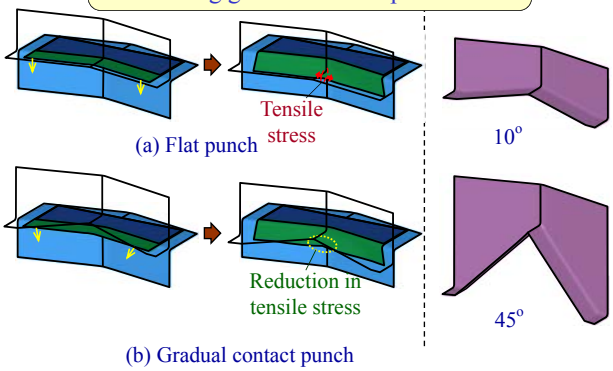
Improvement of limiting stretch flanging ratio (JSC980Y, c=15%)



Reduction in tensile stress at corner using gradual contact punch

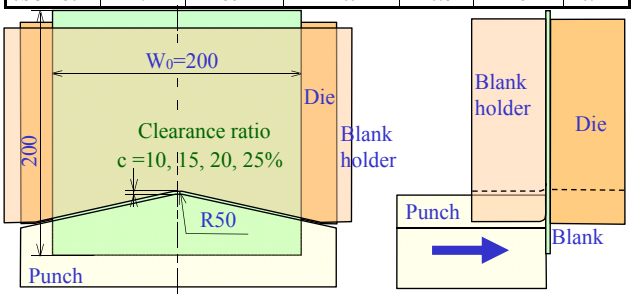


Reduction in tensile stress at corner using gradual contact punch

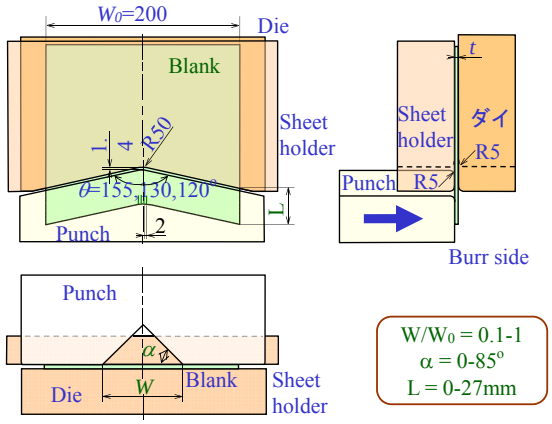


Shearing conditions

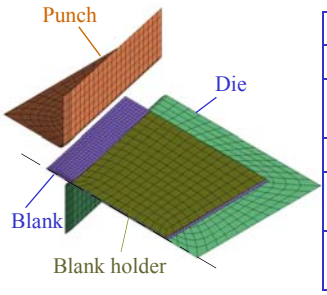
Sheet	Thick-ness /mm	Yield stress /MPa	Tensile strength /MPa	Elonga-tion /%	Reduction in area /%	n-value
JSC780Y	1.4	395	847	18.8	66	0.15
JSC980Y	1.4	660	1014	16.4	45	0.15
JSC1180Y	1.2	864	1209	10.8	46	0.14



Stretch flanging conditions

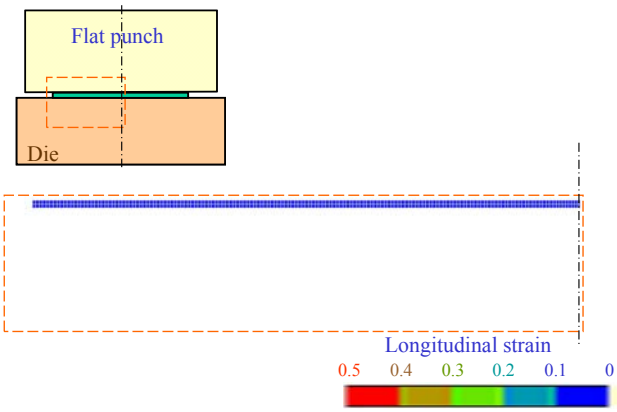


Calculated conditions of stretch flanging

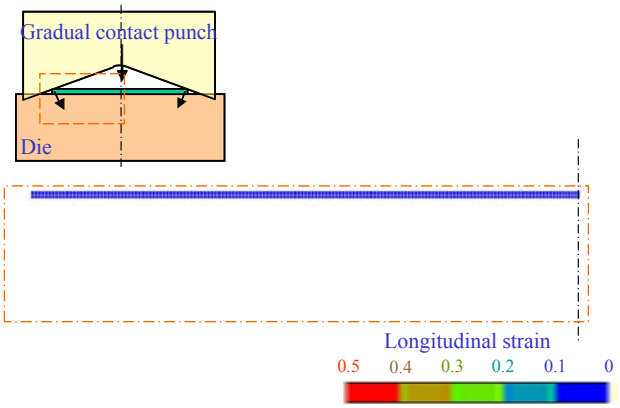


Software	LS-DYNA
Symmetry	1/2 model
Sheet	Elastic-plastic shell elements
Tools	Rigid
Coefficient of friction	0.15
Punch speed	100mm/s

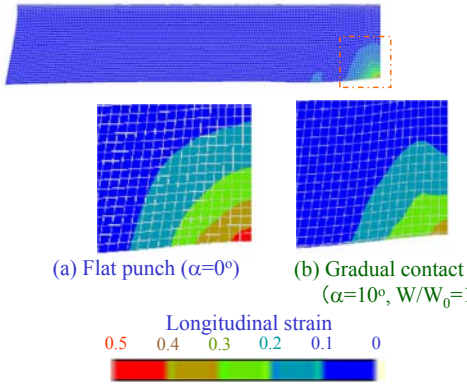
Distribution of longitudinal strain by flat punch (JSC780, α=0°, L=18mm)



Distribution of longitudinal strain by gradual contact punch (JSC780, α=10º , W/W0=1.0, L=18mm)



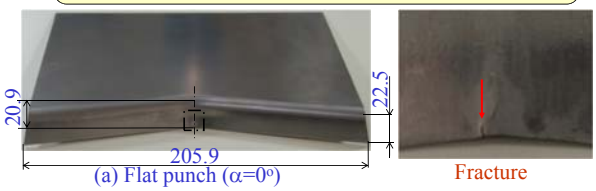
Distribution of longitudinal strain by gradual contact punch (JSC780, L=17mm)



(a) Flat punch (α=0º)

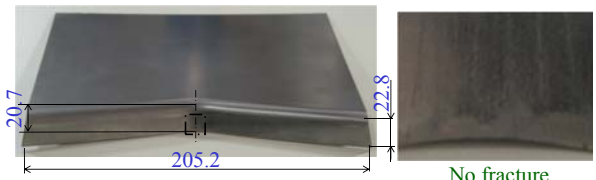
(b) Gradual contact punch (α=10º, W/W_0=1.0)

Prediction of fracture at corner of 780MPa sheet using gradual contact punch



(a) Flat punch (α=0º)

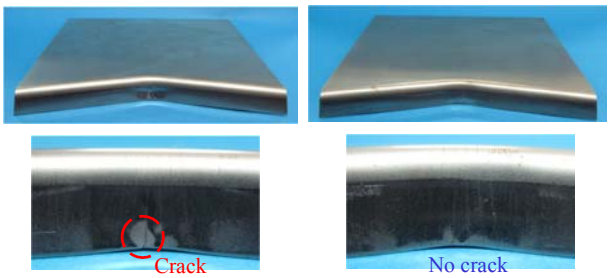
Fracture



(b) Gradual contact punch (α=10º, W/W_0=1.0)

No fracture

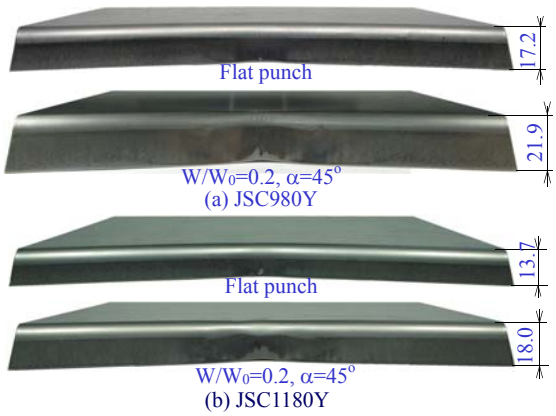
Prediction of fracture at corner of 980MPa sheet using gradual contact punch



(a) Flat punch, α=180º

(b) Gradual contact punch, α=170º

Improvement of limiting flange height by gradual contact punch



(a) JSC980Y

(b) JSC1180Y