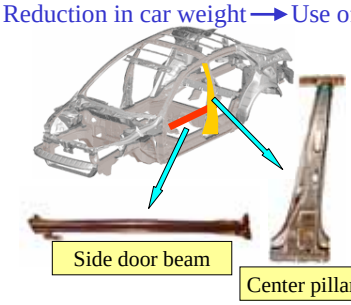
Warm and Hot Stamping of Ultra High Strength Steel Sheets Using Rapid Resistance Heating

K. Mori
Toyohashi University of Technology, Japan

Reduction in car weight → Use of high strength steel sheets



Ultra high strength steel sheet > 1GPa

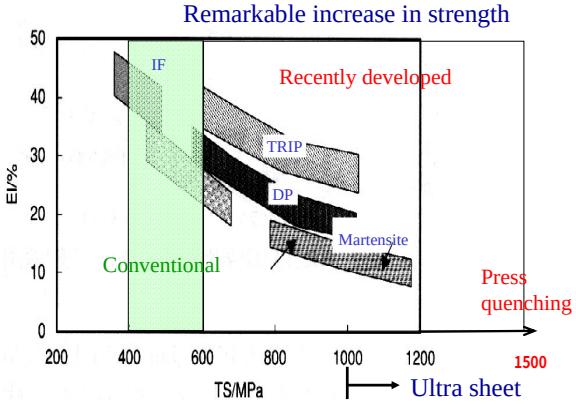
1) Ultra high strength steel sheets
2) Resistance heating
3) Warm and hot stamping
4) Quenching in hot stamping
5) Prevention of oxidation in hot stamping using oxidation preventive oil
6) Warm and hot shearing
7) Warm and hot spline forming

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

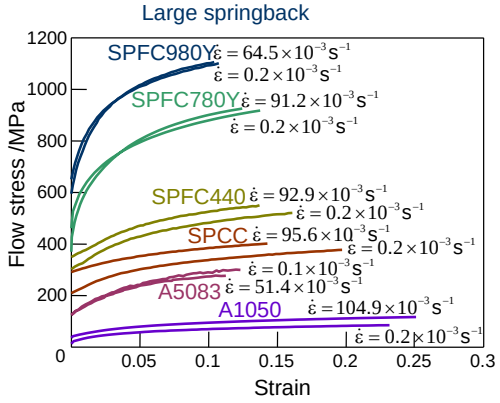
Strength of high strength steel sheets

Remarkable increase in strength



Flow stress curve of sheets at room temperature

Large springback



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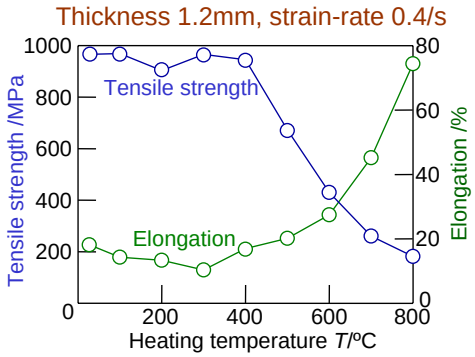
Variations in tensile strength and elongation with temperature for SPFC980Y



Forming of ultra high strength steel sheets

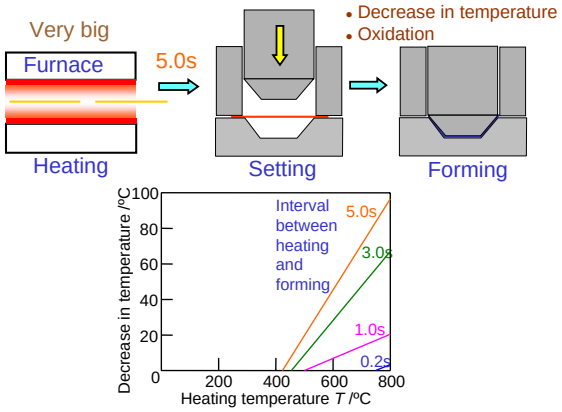
Springback: large
Formability: small

Warm and hot stamping
Reduction in forming load
Increase in formability

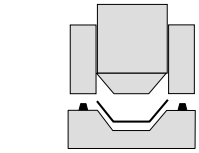
Heating of sheet ?

Al, Mg, stainless steel: low temperature
Steel: high temperature(>500ºC)

Conventional warm and hot stamping



Warm and hot stamping using rapid resistance heating



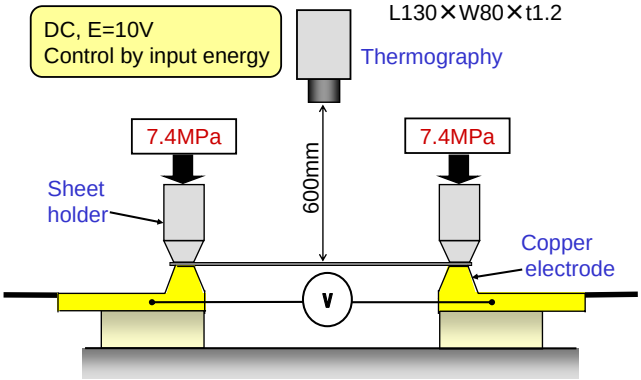
Direct heating into dies

Joule heat

Prevention of drop in temperature
Reduction in oxidation

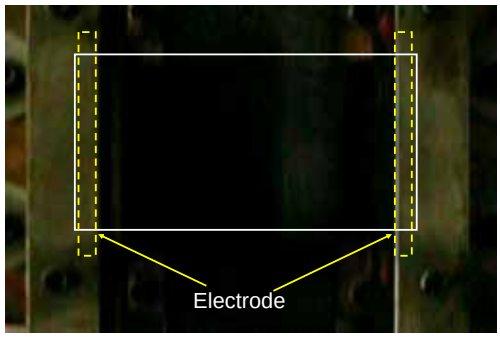
Resistance heating and forming

Measurement of temperature distribution in sheet in resistance heating

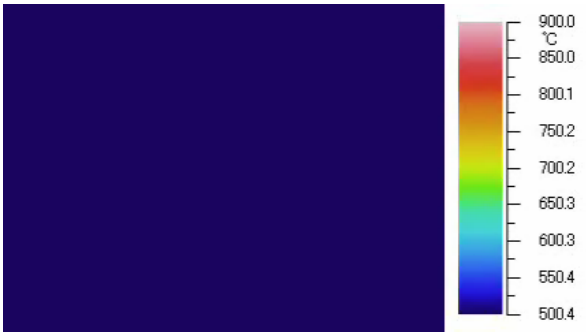


Resistance heating

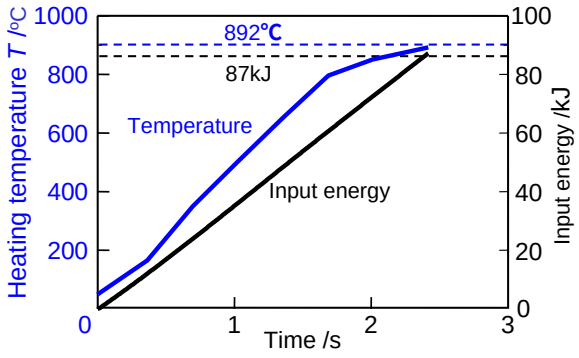
SPFC980, thickness: 1.2mm, Power: 85kJ (10V, 2sec)



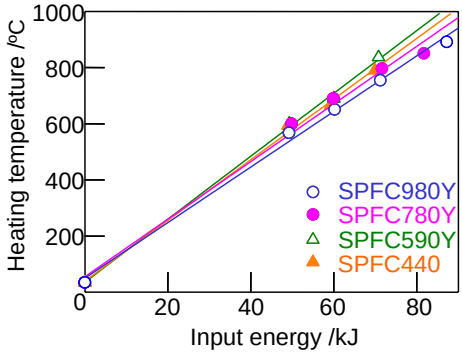
Distribution of temperature in resistance heating of rectangular sheet measured by infrared thermography for SPFC980Y



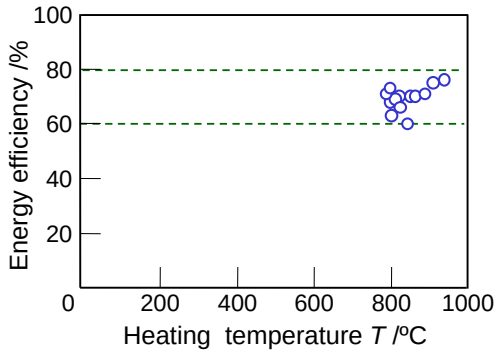
Variations in temperature and input energy in resistance heating of SPFC980



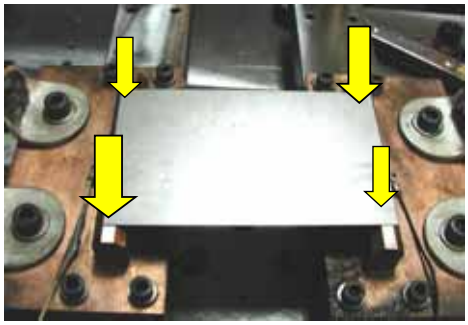
Relationship between measured heating temperature and input energy



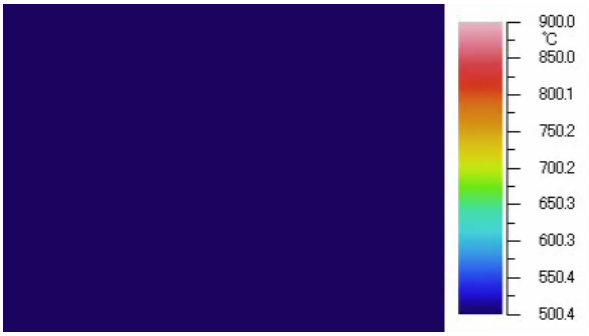
Energy efficiency of resistance heating



Inhomogeneous contact of sheet with electrode



Distribution of temperature measured by infrared thermography for inhomogeneous contact with electrode



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3) Warm and hot stamping

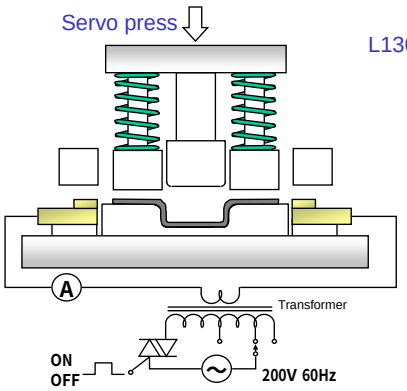
4) Quenching in hot stamping

5) Prevention of oxidation in hot stamping using oxidation preventive oil

6) Warm and hot shearing

7) Warm and hot spline forming

Hat-shaped bending using resistance heating



L130×W20×t1.2

Heating: 0.96s

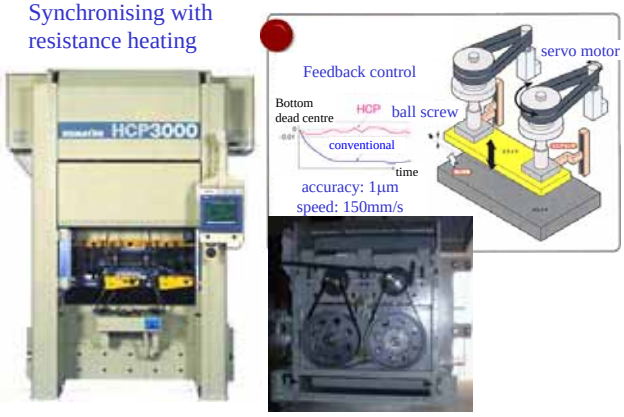
0.26s

Forming

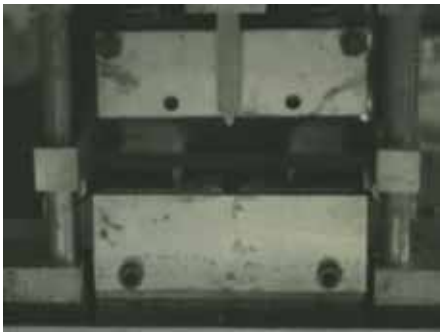
Holding: 3.5s

CNC Servo Press (80tonf)

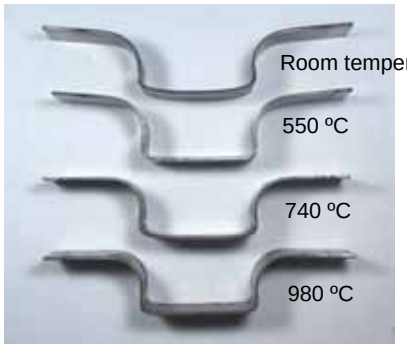
Synchronising with resistance heating



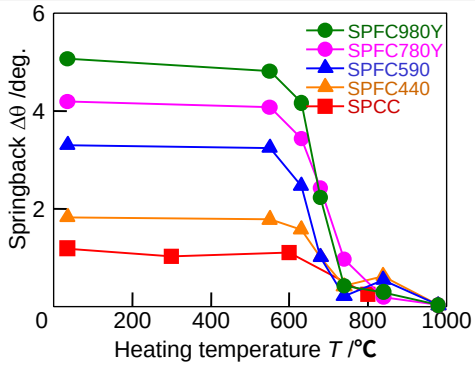
Hat-shaped bending using resistance heating at 980 ºC



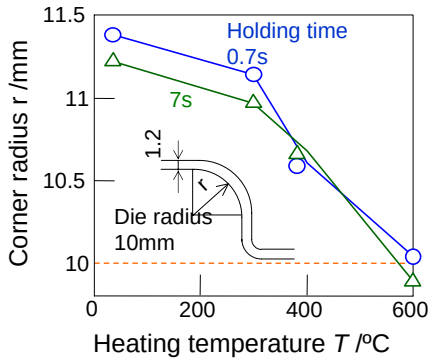
Products formed by hat-shaped bending of SPFC980Y at different heating temperatures



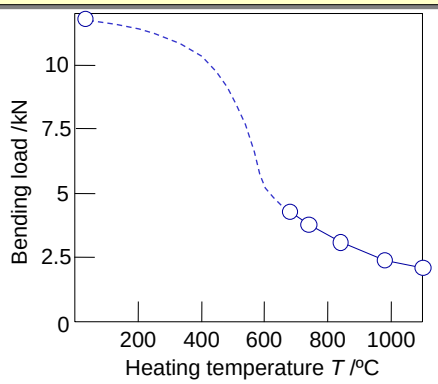
Relationships between springback and heating temperature in hat-shaped bending of various sheets



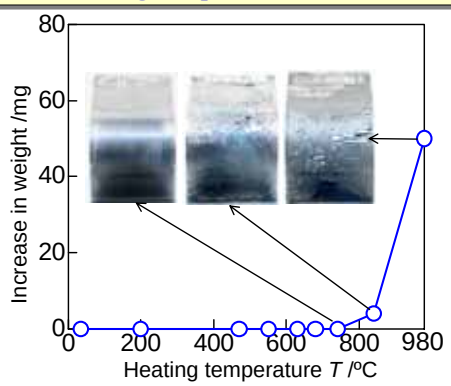
Relationship between corner radius of bent sheet and heating temperature for SPFC980Y



Relationship between bending load and heating temperature

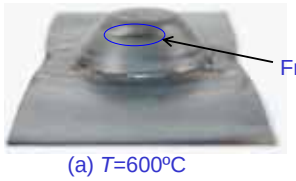


Relationship between amount of oxidation of bent sheet and heating temperature for SPFC980Y



Deep drawing of SPFC980Y rectangular sheet for 800ºC

Formed products in deep drawing of SPFC980Y rectangular sheet



(a) *T*=600ºC

(b) *T*=800ºC

1) Ultra high strength steel sheets

2) Resistance heating

3) Warm and hot stamping

4) Quenching in hot stamping

5) Prevention of oxidation in hot stamping using oxidation preventive oil

6) Warm and hot shearing

7) Warm and hot spline forming

Quenching test of ultra high tensile strength sheet without deformation

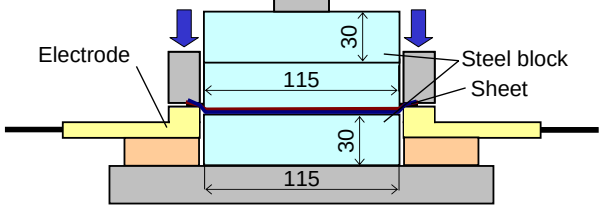
SPFC980Y

C	Si	Mn	P	S
0.14	1.00	2.23	0.01	0.004

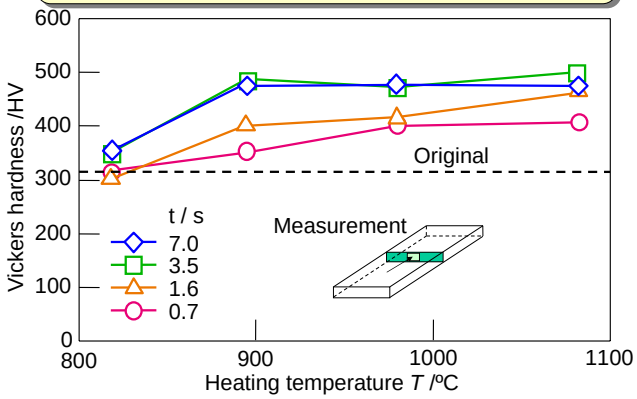
L130×W20×t1.2

From austenite to martensite

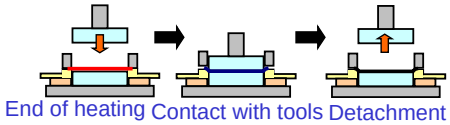
Heating temperature and holding time

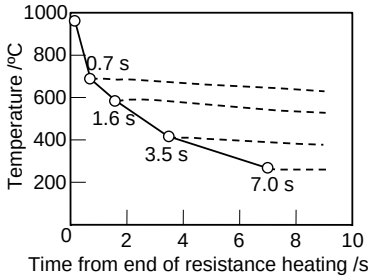


Relationship between Vickers hardness and heating temperature for different holding times at bottom dead centre obtained from quenching test

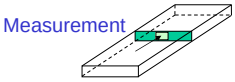


Cooling curve of sheet at T=980 ºC for different holding times





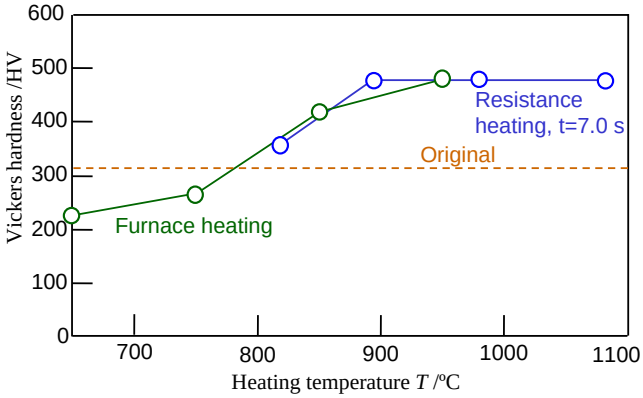
Microstructures at T=980 ºC for two holding times



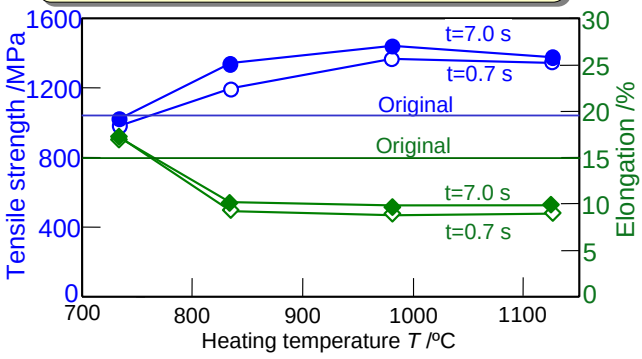
Ferrite and fine pearlite Martensitic

(a) Original (b) t=0.7s (c) t=7.0s

Comparison between hardnesses obtained from resistance heating and furnace heating for t=7.0s



Variations in tensile strength and elongation with heating temperature



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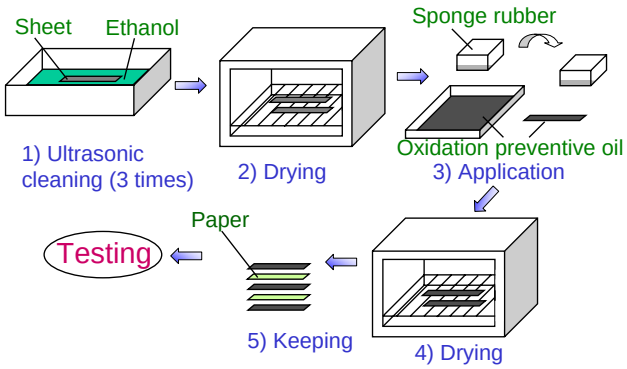
Oxidation preventive oils used for hot stamping

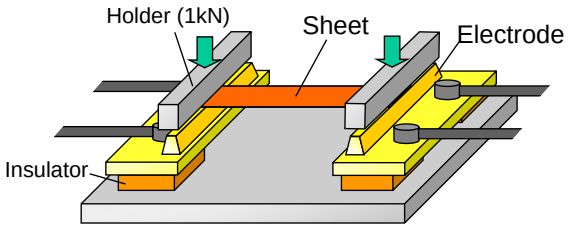
840 ºC

Oxidation preventive oil	A	B	C	D
Element	K, B, C, Na	Si, Na	Ca	C
Oxidation prevention	Liquefied film	Sacrificial oxidation		

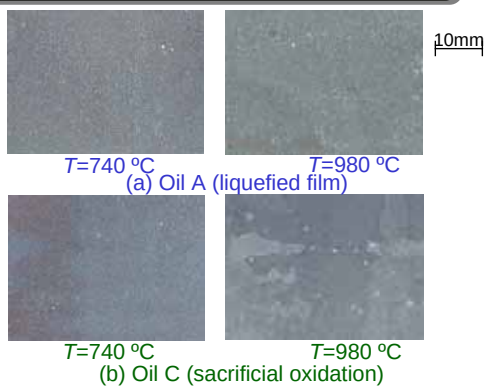
Coating of sheets with oxidation preventive oil



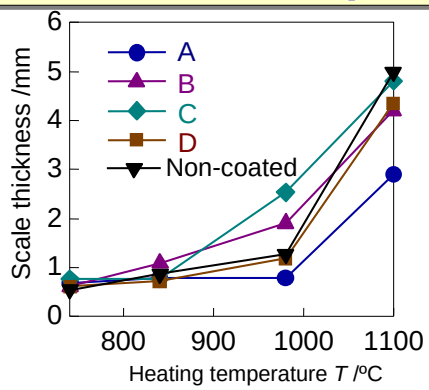
Resistance heating of sheet for evaluation of oxidation preventive oils



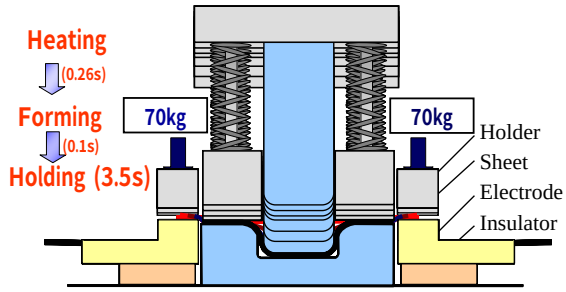
Oxidation on surface of heated sheet for oxidation preventive oils



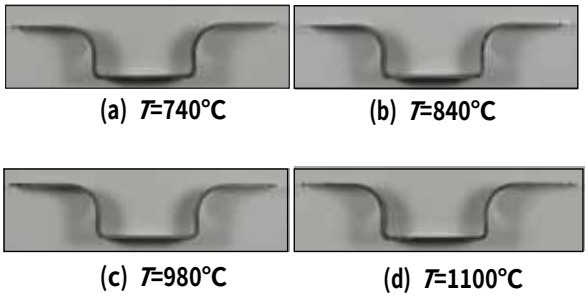
Relationships between scale thickness and heating temperature for different oxidation preventive oils



Hot hat-shaped bending using resistance heating



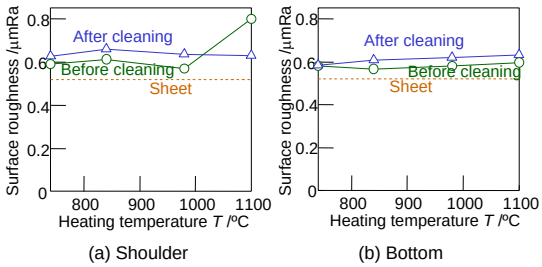
Hat-shaped bent sheet of oil-coated SPFC980



Scale on surface of bent sheet before and after cleaning

10% phosphoric acid

Surface roughness of bent sheet before and after cleaning



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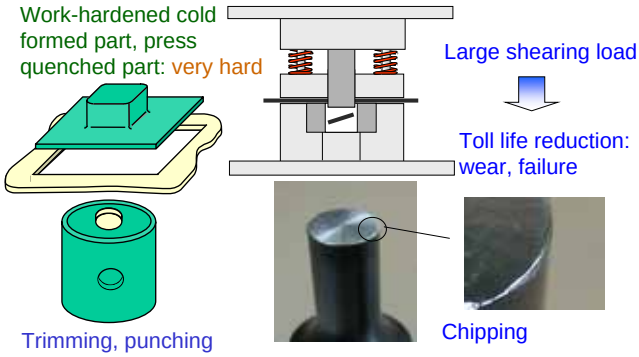
Warm and hot shearing of ultra high strength steel sheet

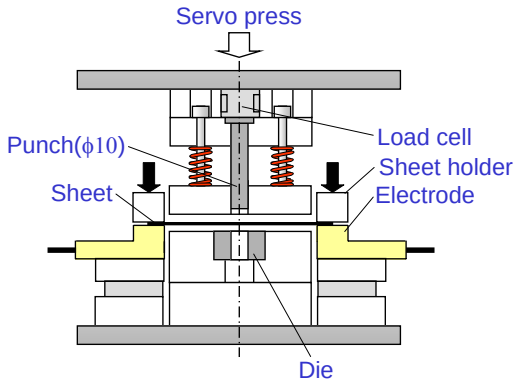


Conditions of warm and hot punching process

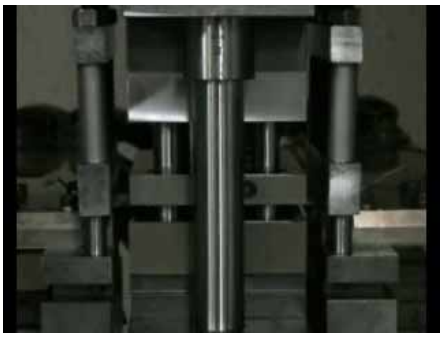
- Sheet
  SPFC980, L130×W50×t2.0
- Punch
  SKH51 (TiCN coating), ϕ10mm

Heating temperature *T* /ºC	650, 700, 830, 970, 1070
Clearance ratio *c* / %	5, 10, 15
Punching speed /mm･s^{-1}	150

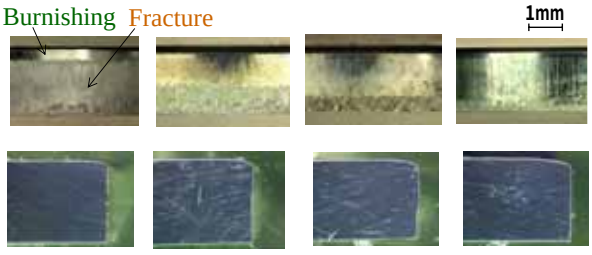
Warm and hot punching



Hot punching of SPFC980Y using resistance heating

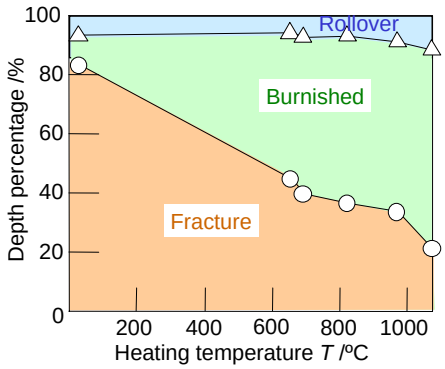


Surface and cross-section of punched edge of SPFC980Y

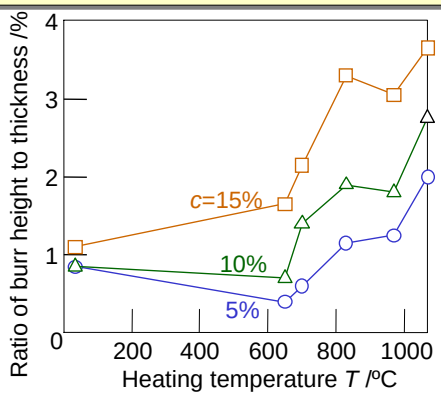


(a) Room temperature (b) 650 ºC (c) 830 ºC (d) 1070 ºC

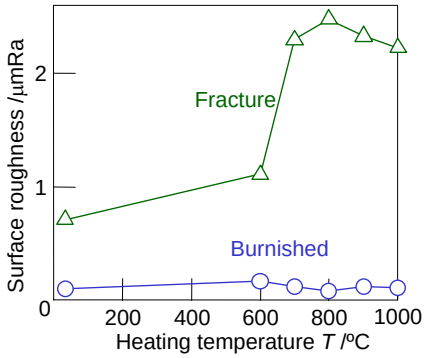
Relationship between percentage of depths of burnished surface, fracture surface and rollover on sheared edge and heating temperature



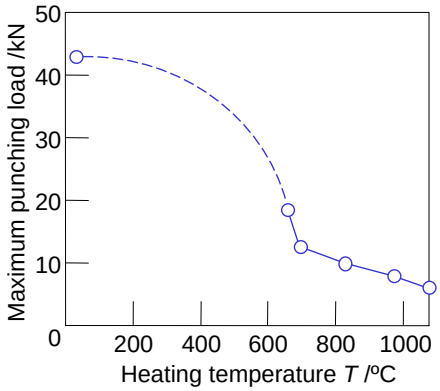
Relationship between ratio of burr height on sheared edge to thickness and heating temperature for different clearance ratios



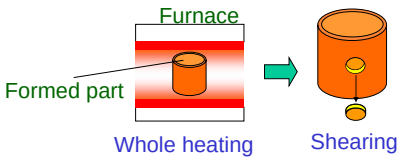
Relationship between roughness of burnished and fracture surfaces on sheared edge and heating temperature for c=5%



Relationship between maximum punching load and heating temperature

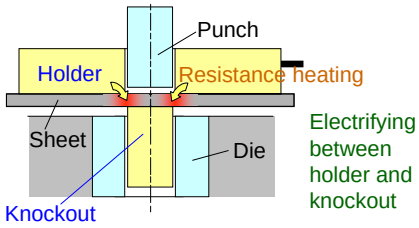


Problem for heating in warm and hot shearing



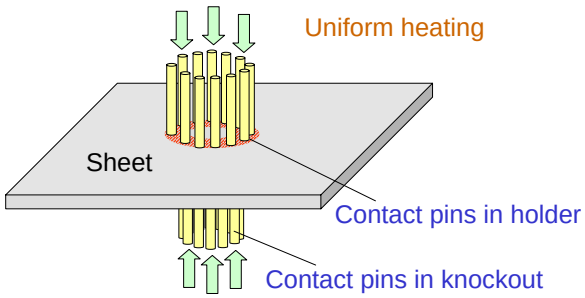
1) Low heating efficiency
2) Low dimensional accuracy
3) Long heating time

Local heating near shearing region

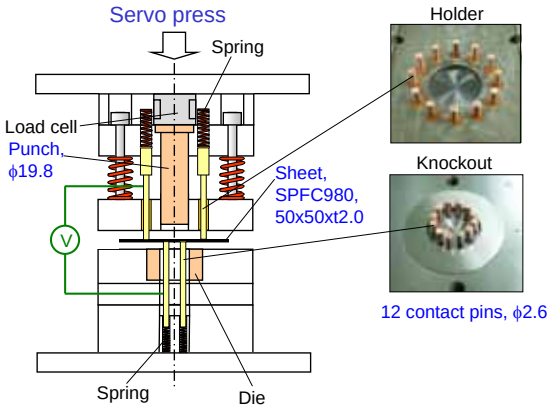


1) High heating efficiency
2) Compact apparatus
3) Small oxidation

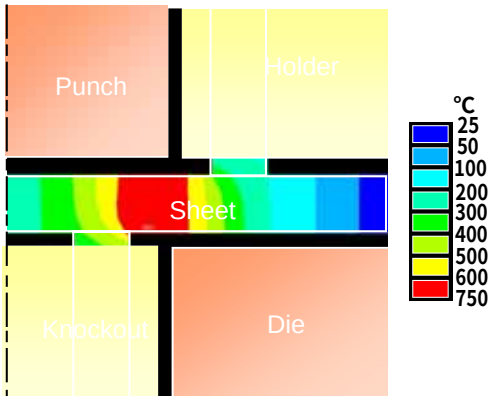
Contact pin electrodes used for local heating



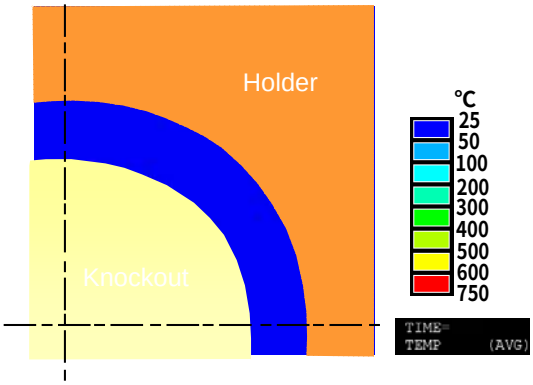
Local heating using contact pins



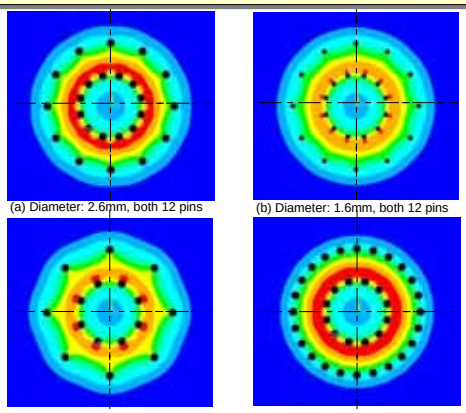
FEM simulation of temperature distribution in local heating



FEM simulation of temperature distribution in local heating



FEM simulation of temperature distribution in local heating



(a) Diameter: 2.6mm, both 12 pins

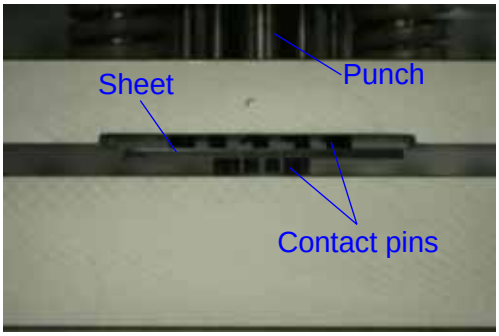
(b) Diameter: 1.6mm, both 12 pins

(c) Diameter: 2.6mm, both 8 pins

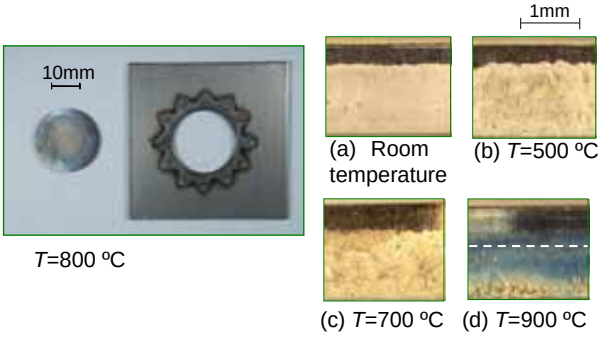
(d) Diameter: 2.6mm, inside: 12 pins, outside: 24 pins

Local heating using contact pins

T=800℃, *v*=150mm/s



Punched sheet for *c*=10% and *v*=150mm/s



T=800 ºC

(a) Room temperature

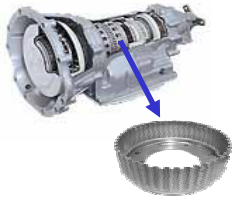
(b) *T*=500 ºC

(c) *T*=700 ºC

(d) *T*=900 ºC

1) Ultra high strength steel sheets
2) Resistance heating
3) Warm and hot stamping
4) Quenching in hot stamping
5) Prevention of oxidation in hot stamping using oxidation preventive oil
6) Warm and hot shearing
7) Warm and hot spline forming

Spline forming of clutch drum

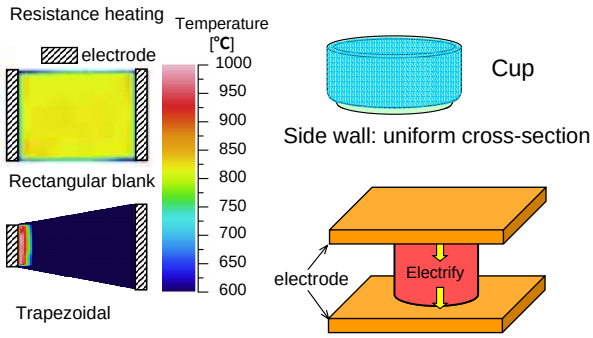


Clutch drum

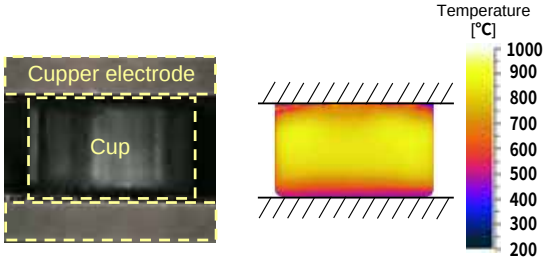
High tensile strength steel

Spline forming

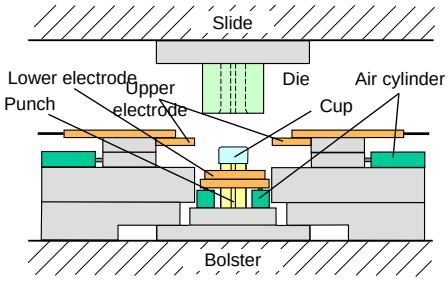
Uniform resistance heating of cup



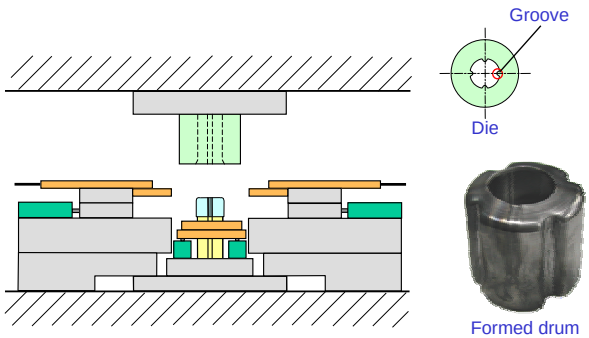
Resistance heating of cup



Spline forming of clutch drum



Spline forming of clutch drum



Formed drum

1) Ultra high strength steel sheets
2) Resistance heating
3) Warm and hot stamping
4) Quenching in hot stamping
5) Prevention of oxidation in hot stamping using oxidation preventive oil
6) Warm and hot shearing
7) Warm and hot spline forming