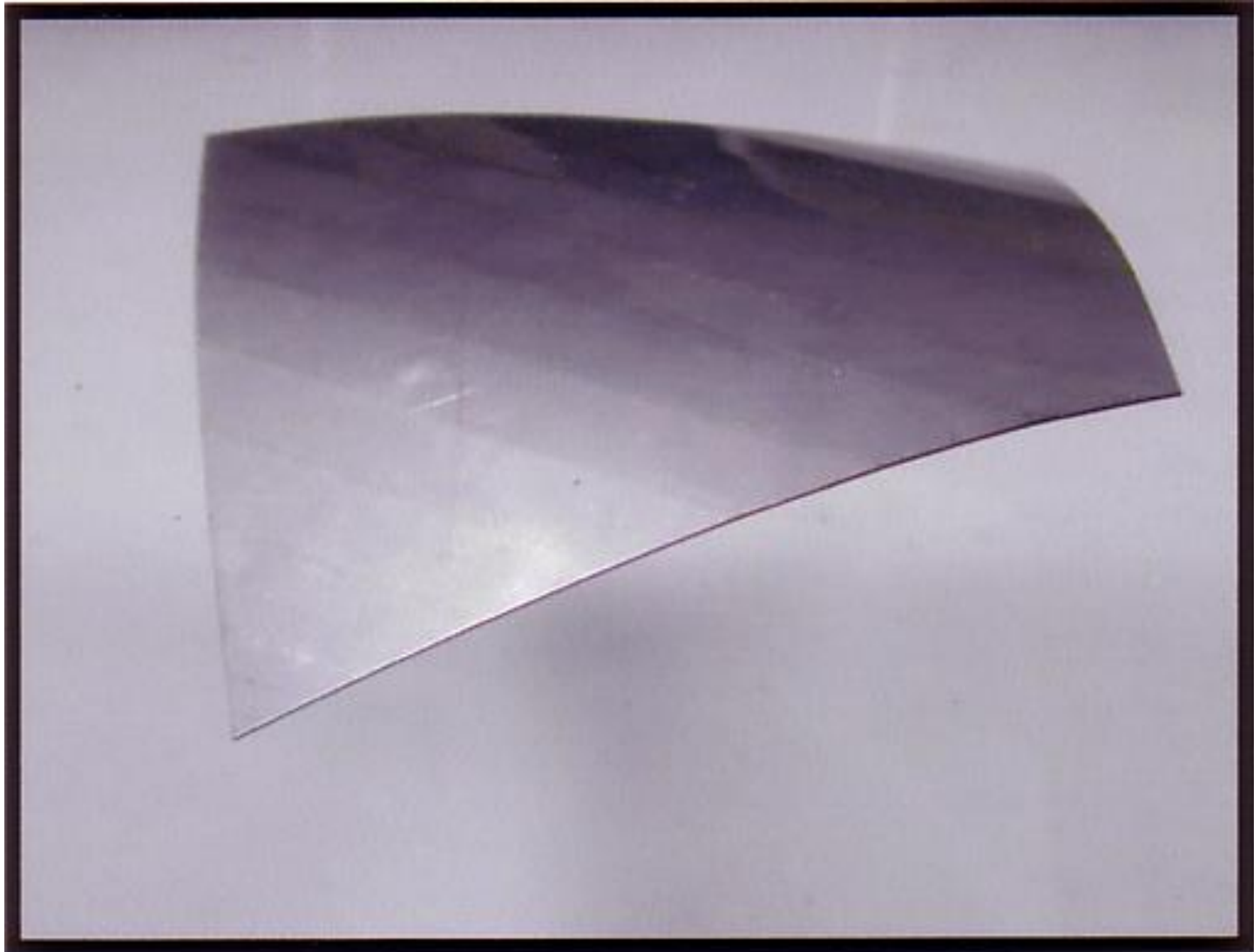


# **Laser Forming of metallic materials**

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**Nagoya University ,Dept. of  
Materials Processing Eng.**

# Laser bending of austenitic stainless steel



# レーザ板曲げ加工実験

温度測定

断面観察

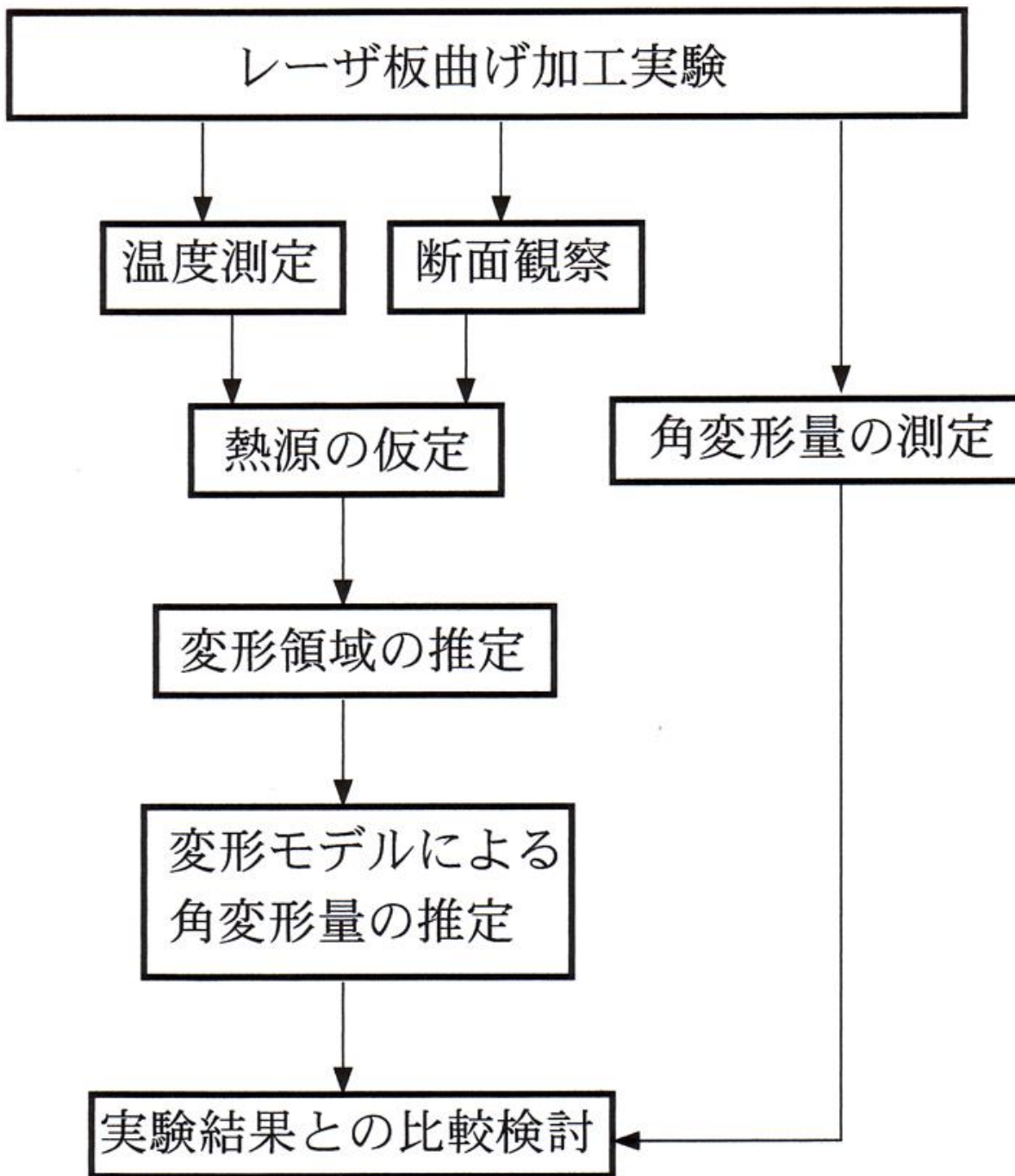
熱源の仮定

角変形量の測定

変形領域の推定

変形モデルによる  
角変形量の推定

実験結果との比較検討



# Experimental set up for laser bending

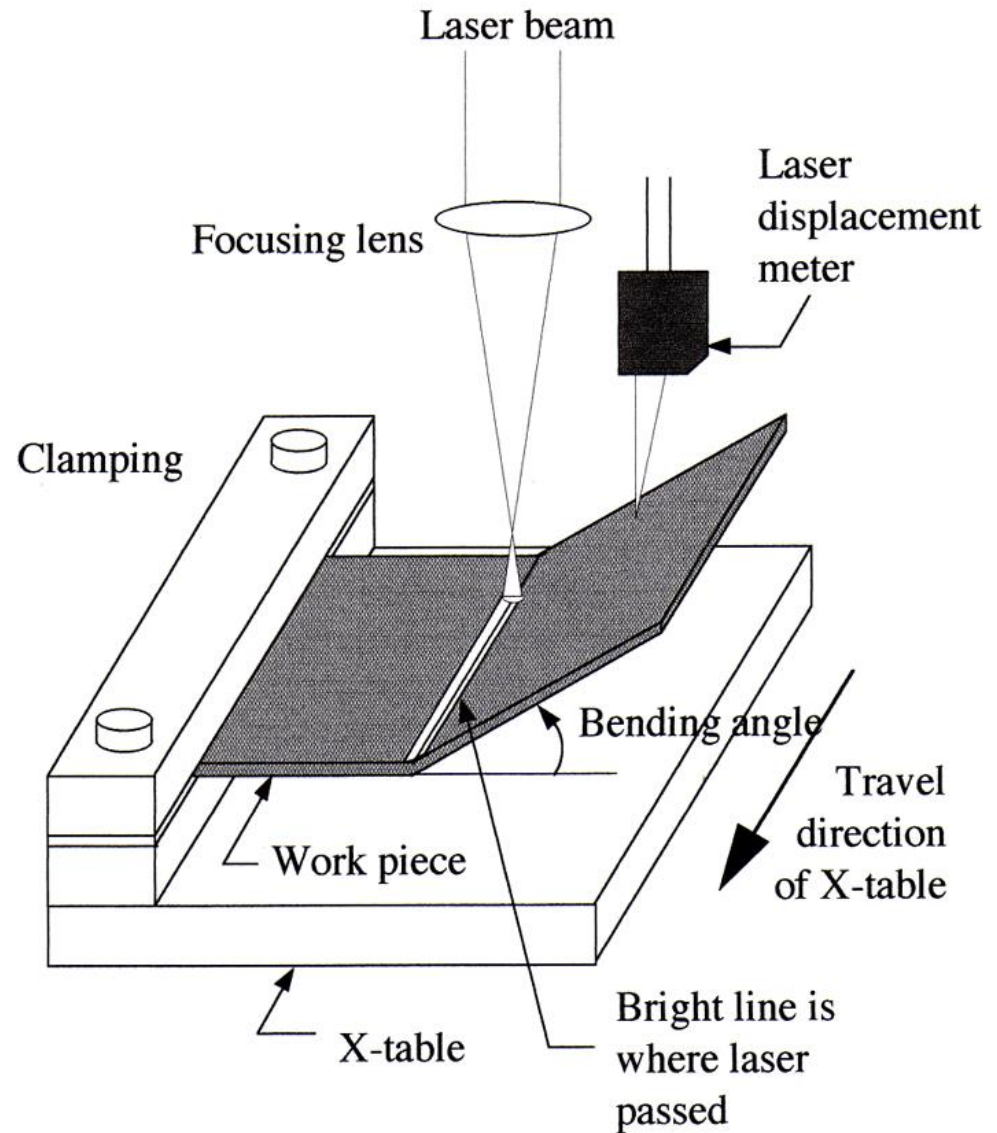


Fig. Schematic drawing of laser bending experiment

# Laser heating condition

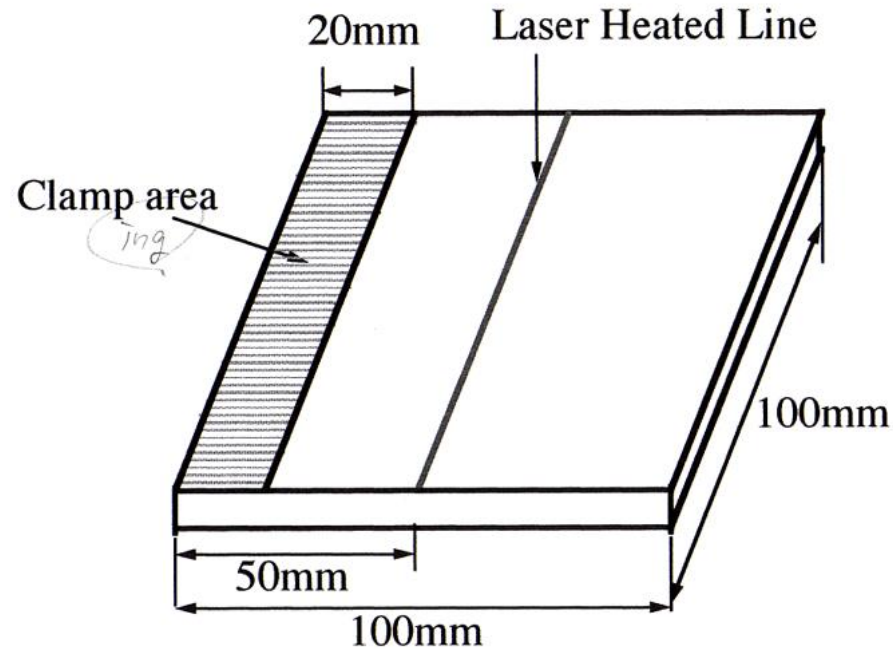


Fig. work piece

Table Welding condition

Thickness of plate	Laser power	Table speed	Spot diameter
0.3mm 0.5mm 1.0mm	310W	30mm/s	3.9mm

# Use of Defocusing beam

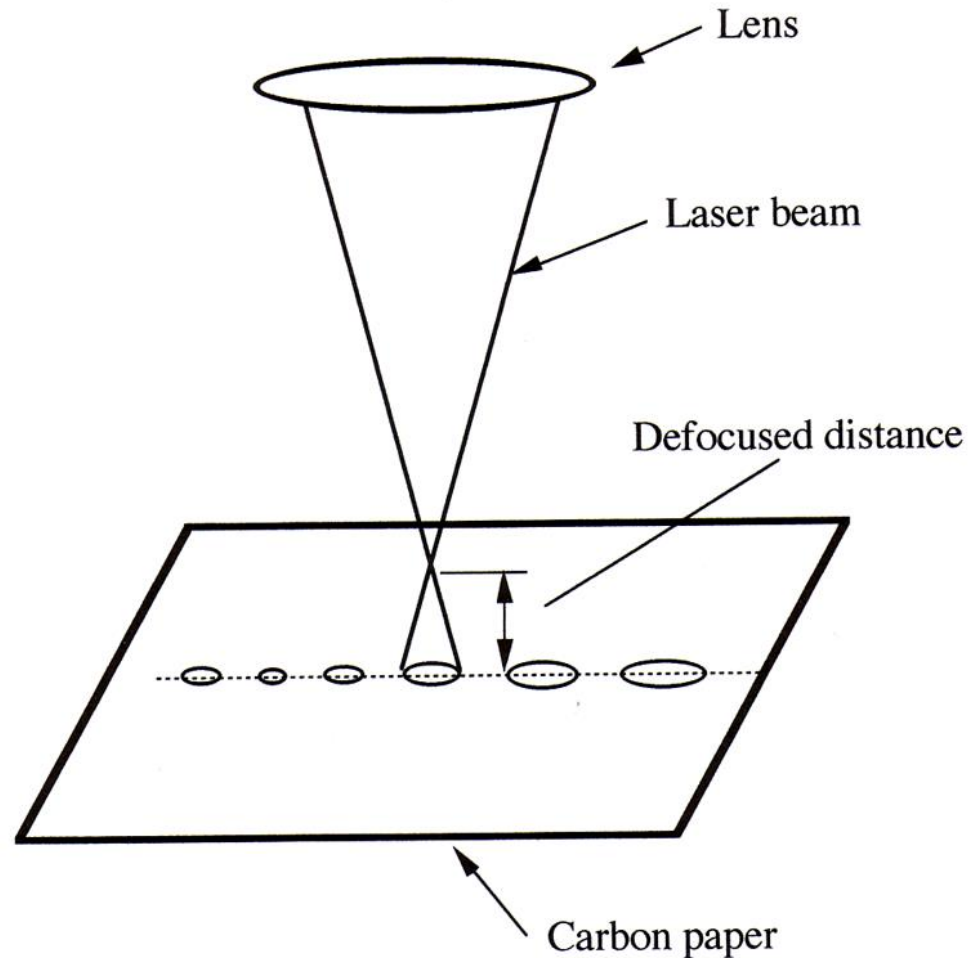


Fig. Diagram of determination of focusing distance with carbon paper

# Measurement of thermal cycle

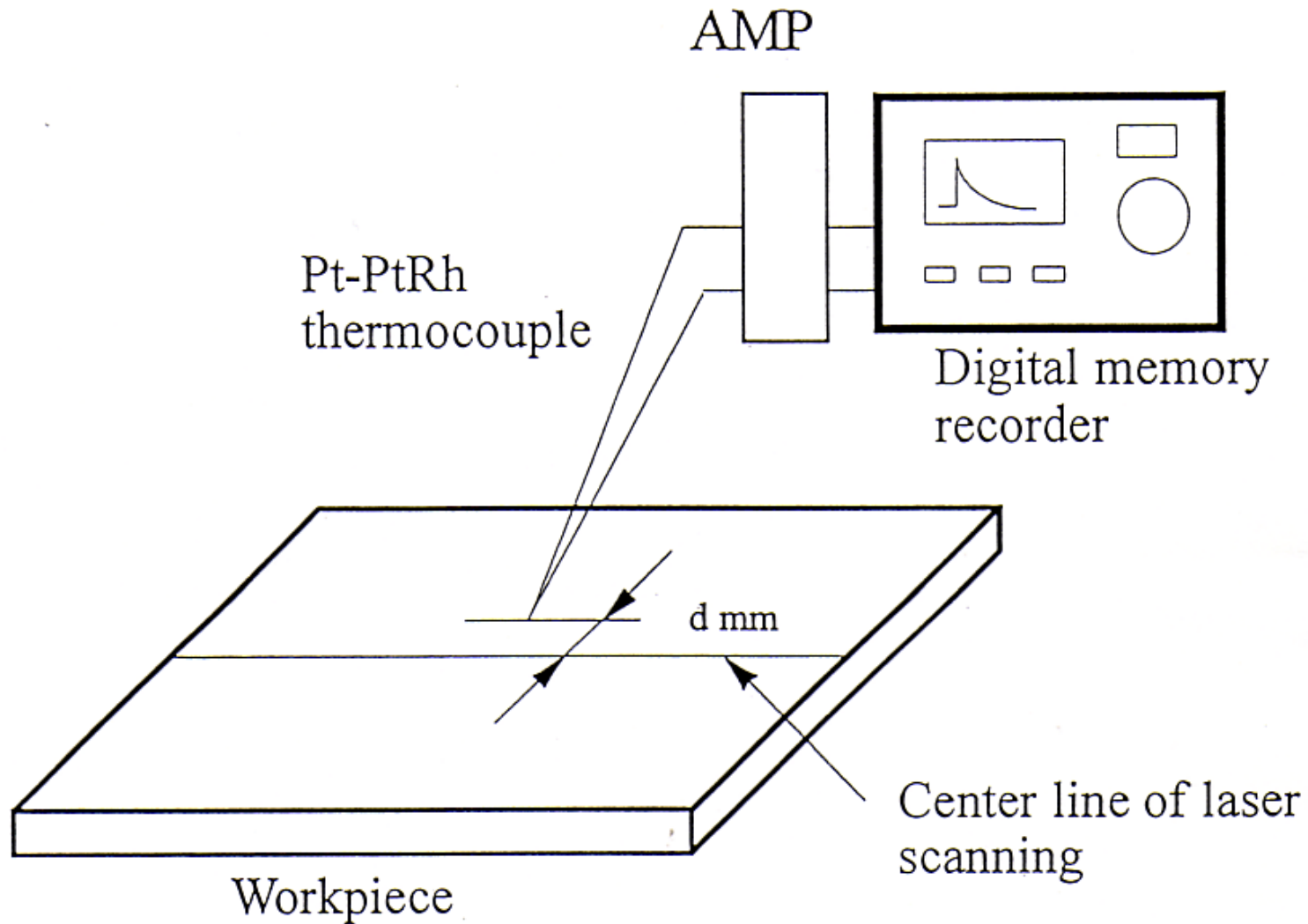




Table Chemical composition of stainless steels (mass%)

Material	Element, mass%							
	C	Si	P	S	Cr	Mn	Mo	Ni
SUS304	0.04	0.36	0.037	0.006	18.12	1.13	—	9.16
SUS410	0.04	0.36	0.022	0.002	12.72	0.32	—	0.08

Table Physical properties of stainless steels

Material	Specific heat ( $10^6 \text{J/m}^3/\text{K}$ )	Thermal conductivity ( $\text{J/m/s/K}$ )	Coefficient of linear expansion ( $10^{-6}/^\circ\text{C}$ )	Thermal diffusivity ( $\text{m}^2/\text{s}$ )	Young's modulus ( $\text{kN/mm}^2$ )
SUS304	3.98	16.3	18.7	$4.1 \times 10^{-6}$	19.7
SUS410	3.57	24.9	11.7	$6.97 \times 10^{-6}$	20.4



### SUS304

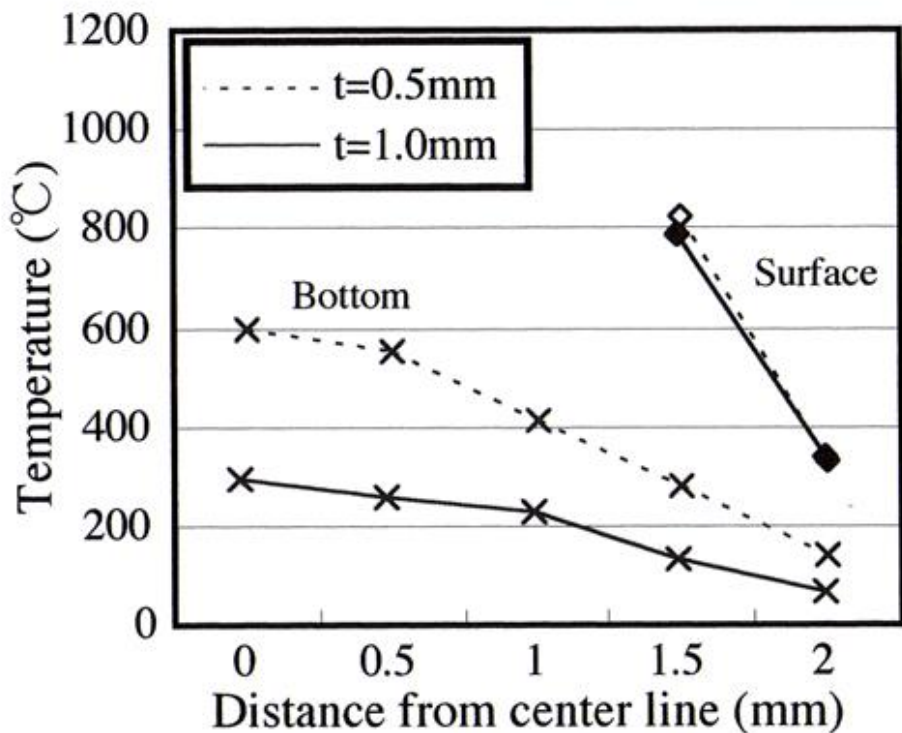


Fig. Relationship between temperature and distance from center line

### SUS410

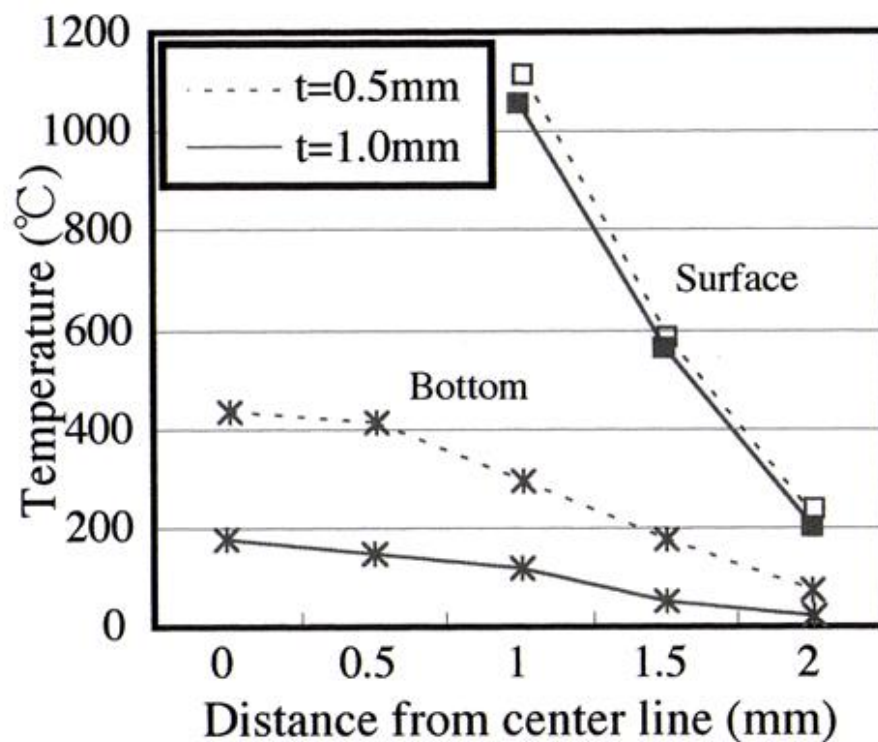


Fig. Relationship between temperature and distance from center line

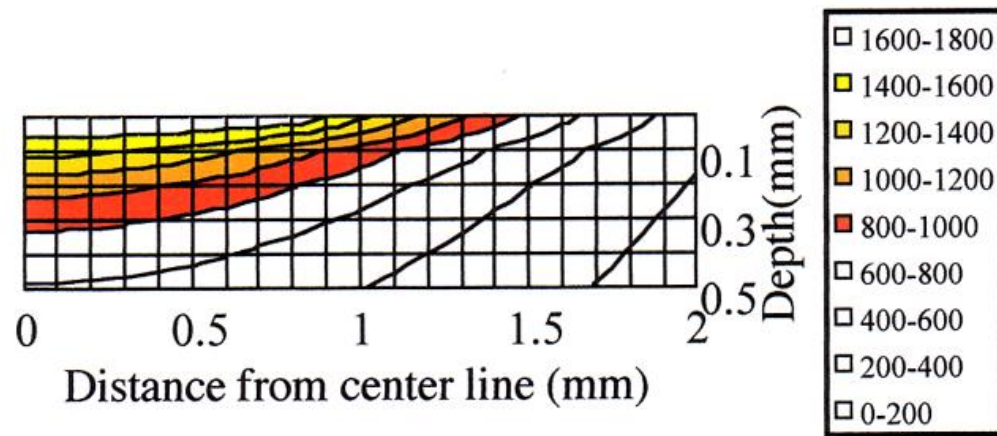


Fig. (a) The isothermal lines of the peak temperature distribution (SUS304 0.5mm thickness)

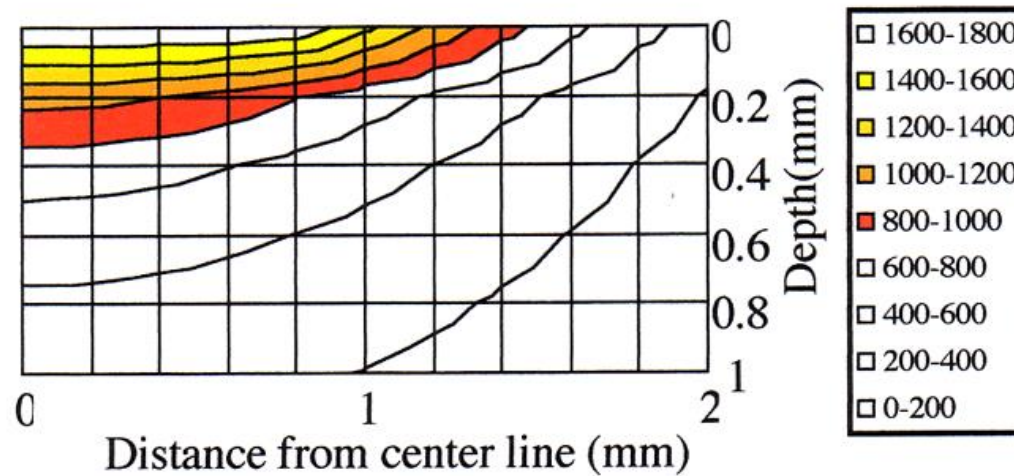


Fig. (b) The isothermal lines of the peak temperature distribution (SUS304 1.0mm thickness)

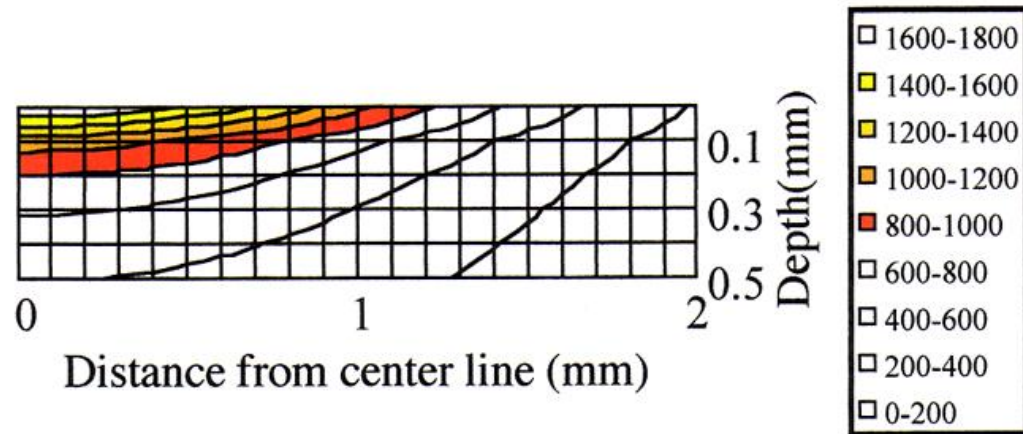


Fig. (a) The isothermal lines of the peak temperature distribution (SUS410 0.5mm thickness)

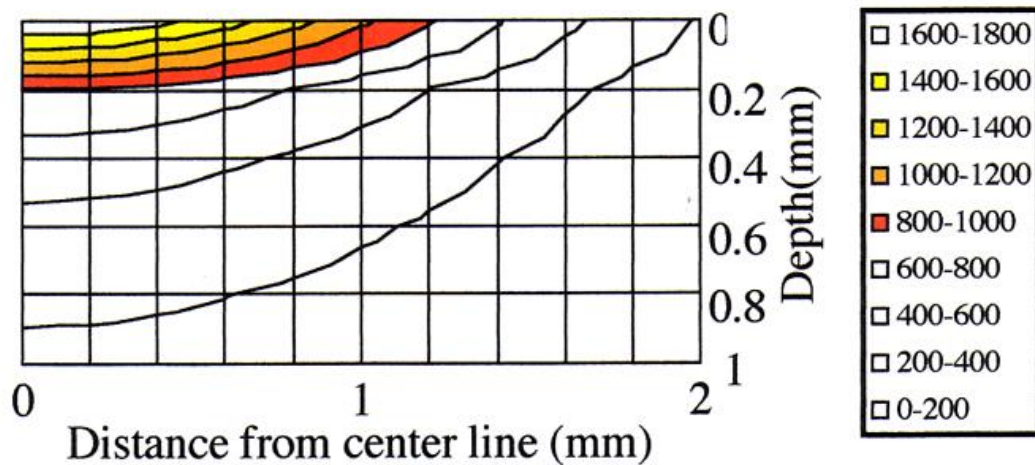
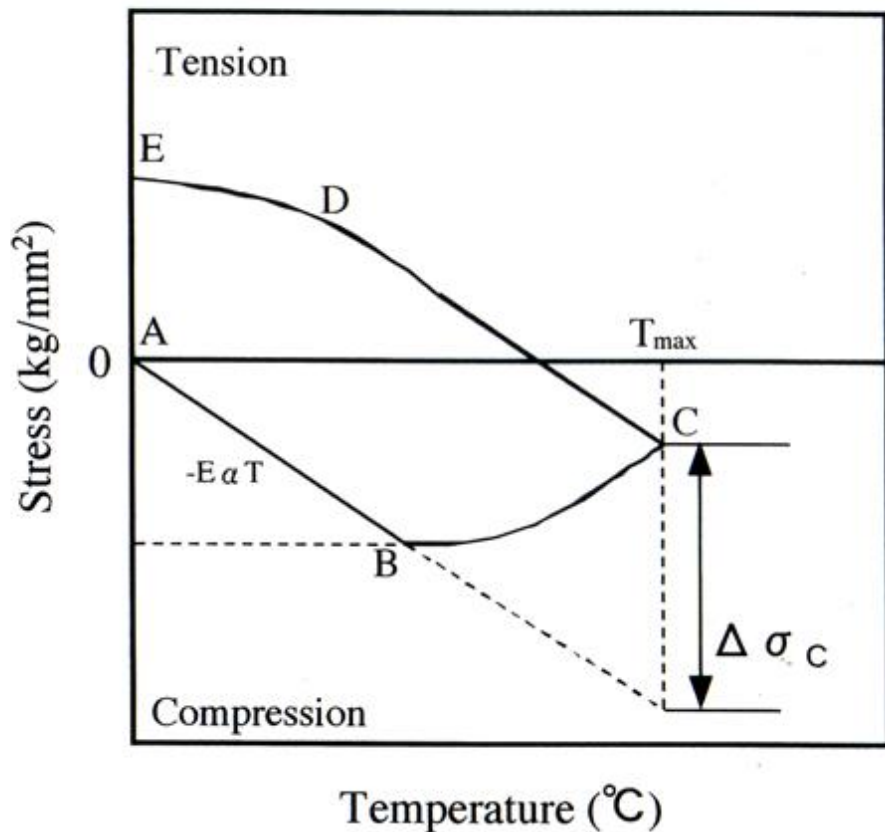
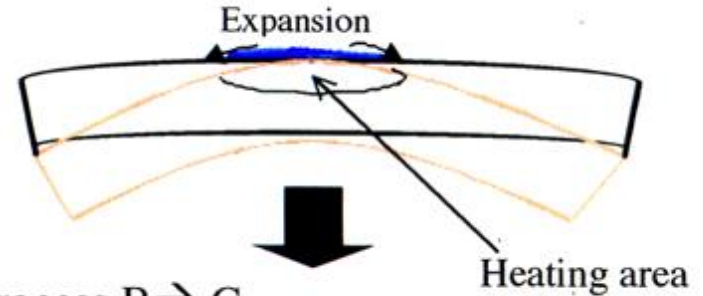


Fig. (b) The isothermal lines of the peak temperature distribution (SUS410 1.0mm thickness)

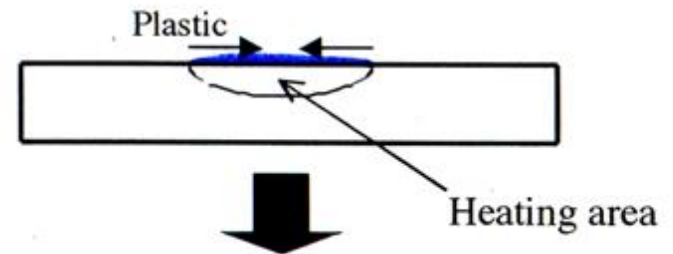
# Deformation model by laser



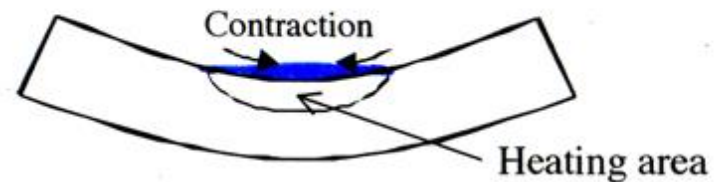
1) Process A  $\rightarrow$  B



2) Process B  $\rightarrow$  C



3) Process C  $\rightarrow$  E



(b) Deformation process

Fig. (a) The typical thermal stress during single thermal cycle



# Stress-temperature curves for different steels

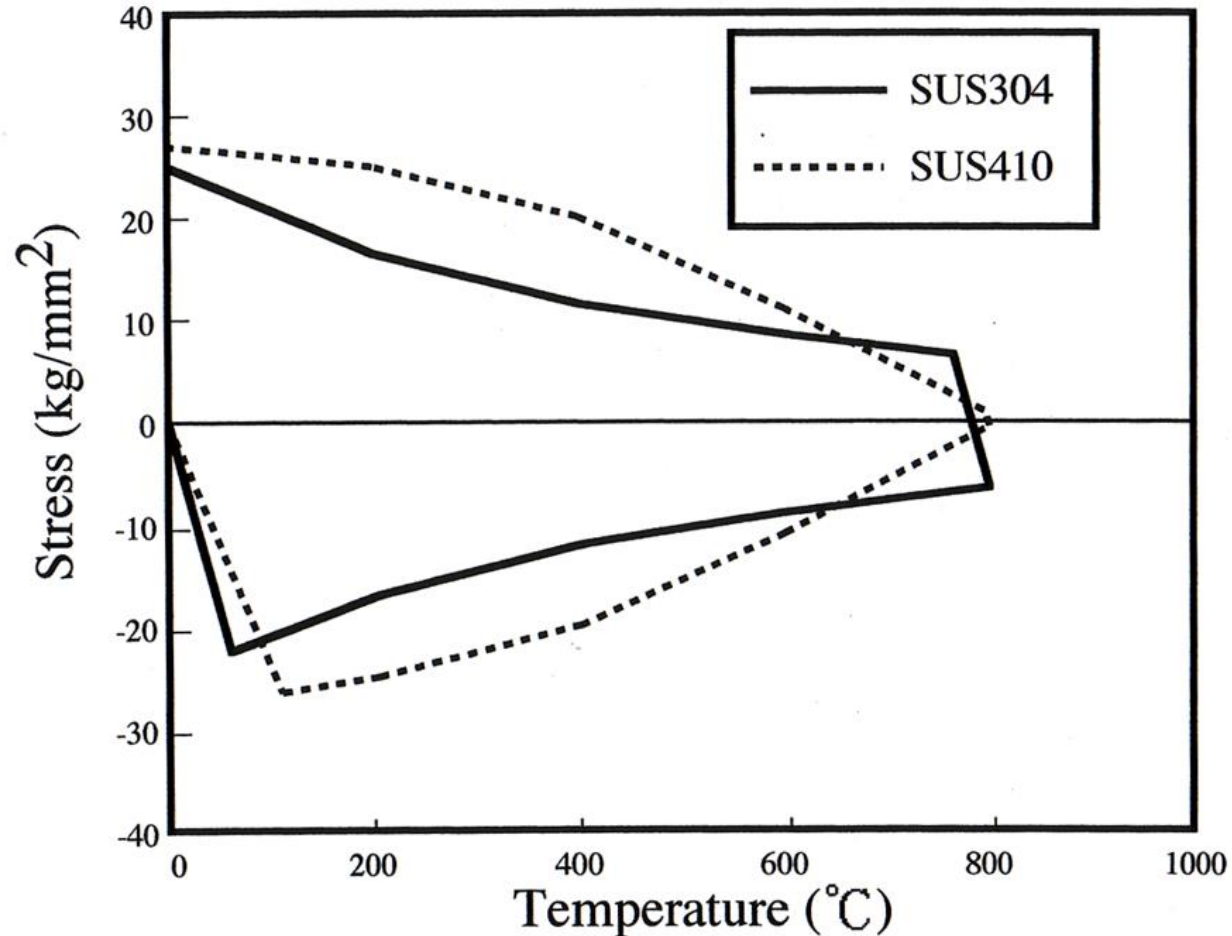
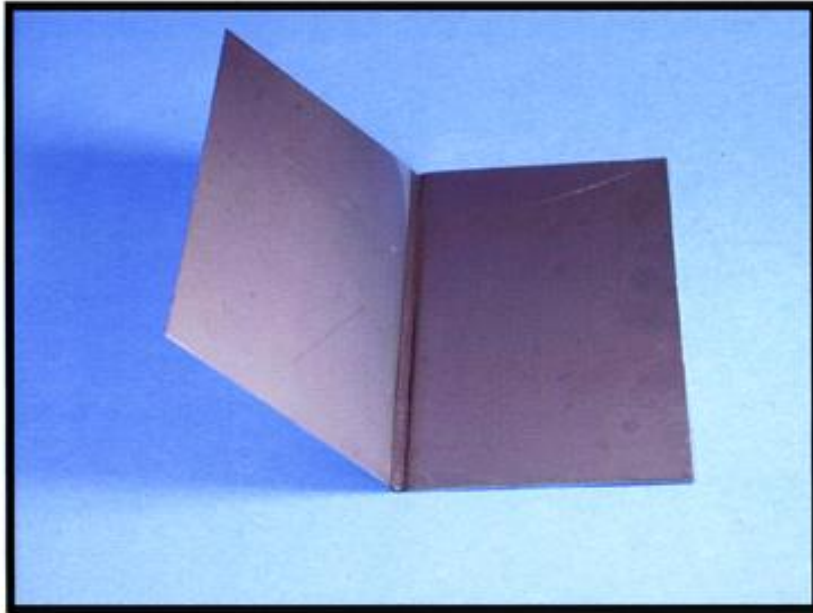


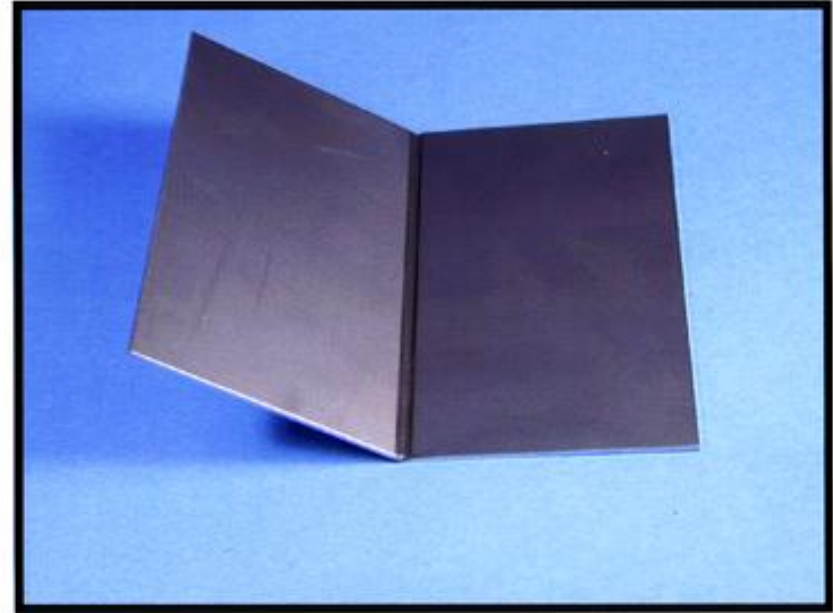
Fig. Thermal stress developed in stainless steel during single thermal cycle

# Result of multi laser scan for bending



Laser power 310W  
Spot diameter 3.9mm  
Table speed 30mm/s  
10pass  
Thickness 0.5mm

10mm



Laser power 310W  
Spot diameter 3.9mm  
Table speed 30mm/s  
10pass  
Thickness 1.0mm

10mm

# Result of multi laser scan for bending

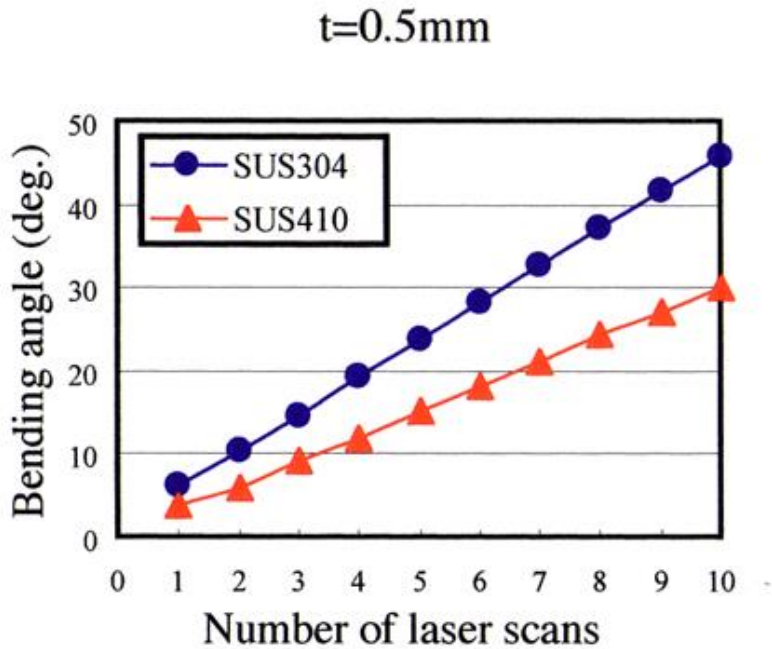


Fig.3-1 Relationship between number of laser scan and bending angle (0.5mm thickness)

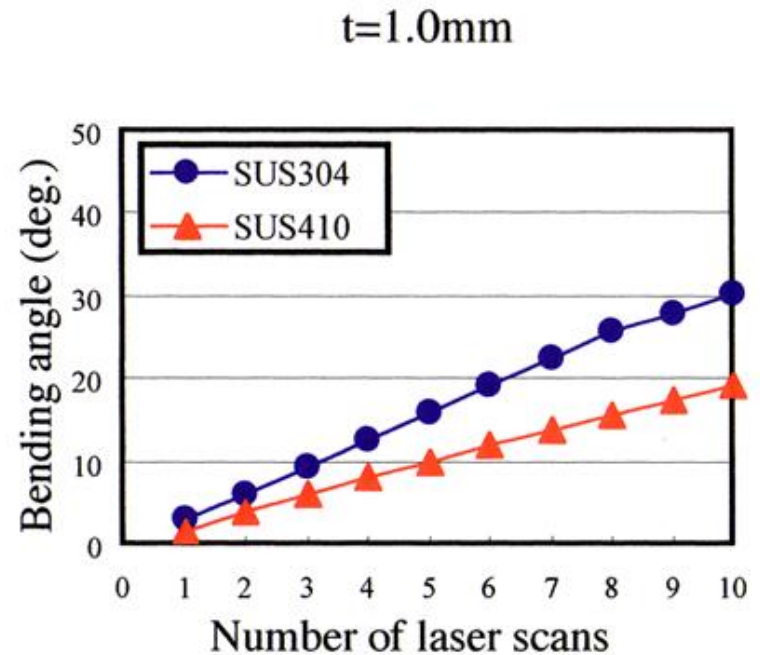
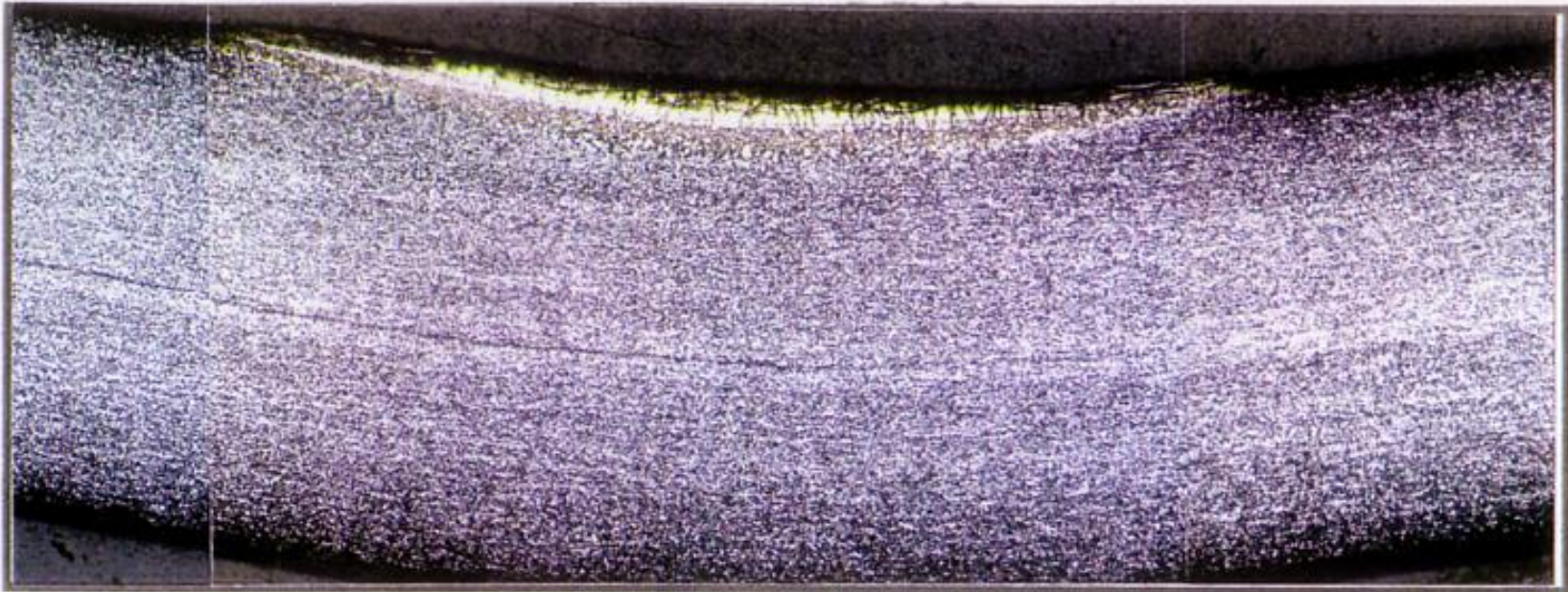


Fig.3-2 Relationship between number of laser scan and bending angle (1.0mm thickness)



# Lateral expansion of bended plate

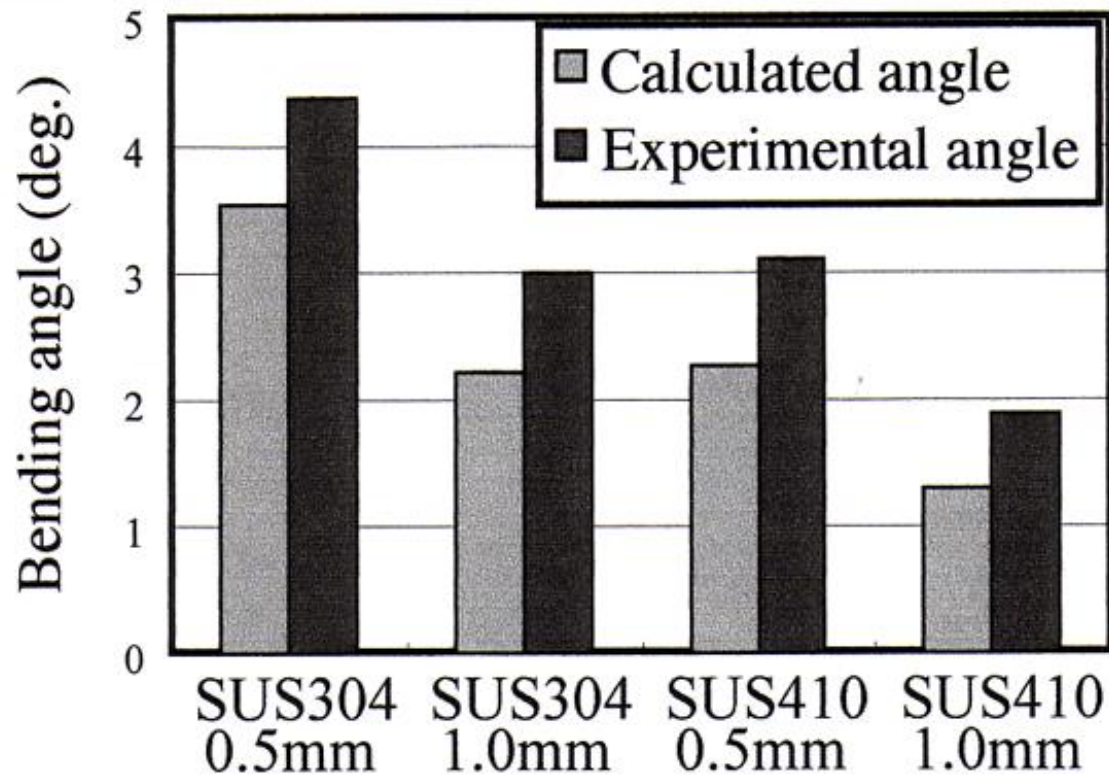


Laser power 310W  
Spot diameter 3.9mm  
Table speed 30mm/s  
10pass  
Thickness 1.0mm

0.5mm

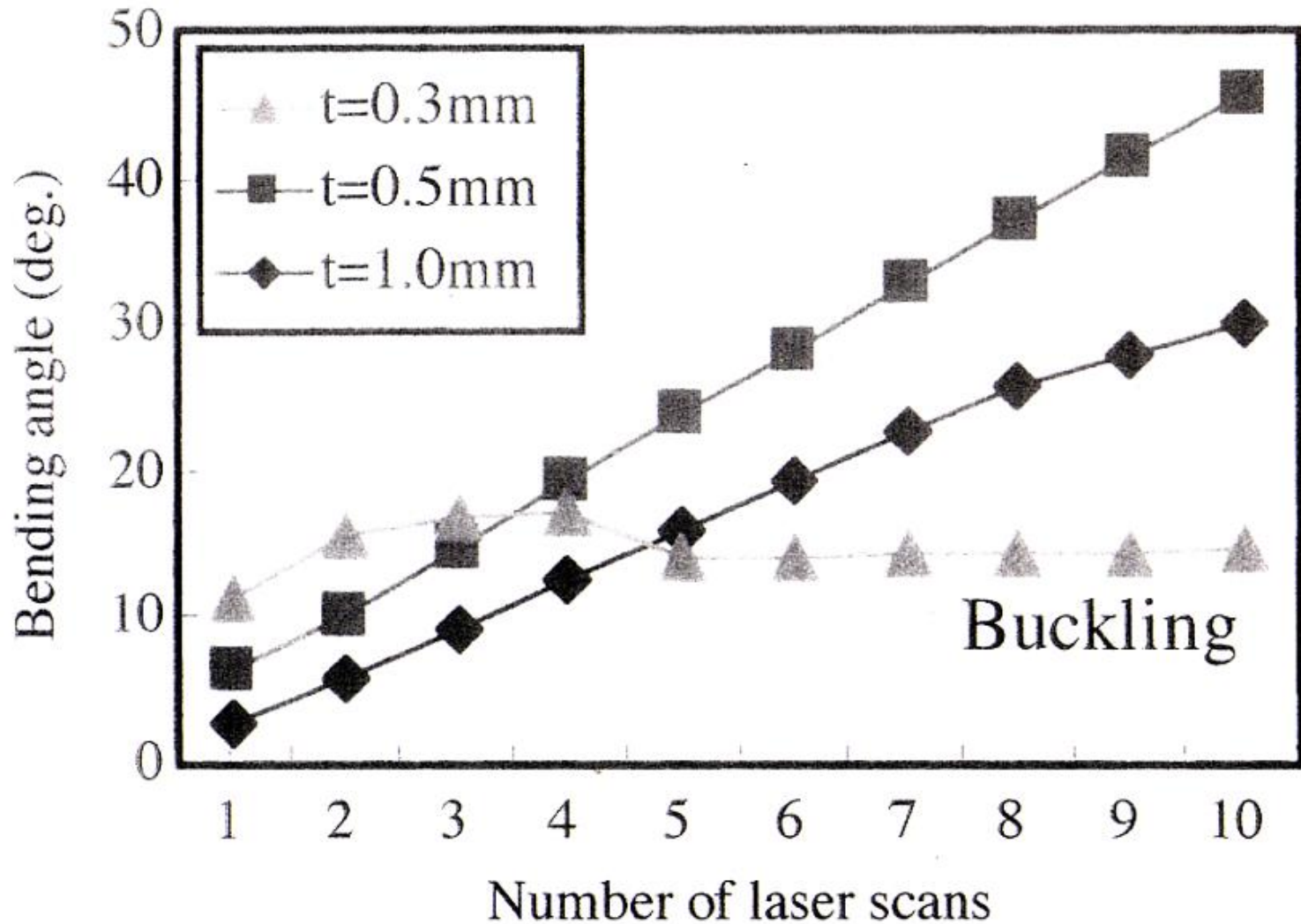
Table The comparison of bending angle in stainless steel

Materials	SUS304	SUS304	SUS410	SUS410
Thickness (mm)	0.5	1.0	0.5	1.0
Strain :top $\epsilon_A$	$1.46 \times 10^{-2}$	$1.46 \times 10^{-2}$	$9.36 \times 10^{-3}$	$9.36 \times 10^{-3}$
Strain :bottom $\epsilon_B$	$4.15 \times 10^{-3}$	$1.44 \times 10^{-3}$	$1.27 \times 10^{-3}$	$4.24 \times 10^{-4}$
Calculated angle (deg.)	3.53	2.22	2.26	1.34
Experimental angle (deg.)	4.38	3.01	3.10	1.83





# Effect of plate thickness on bending angle



# Result of laser bending for stainless steels

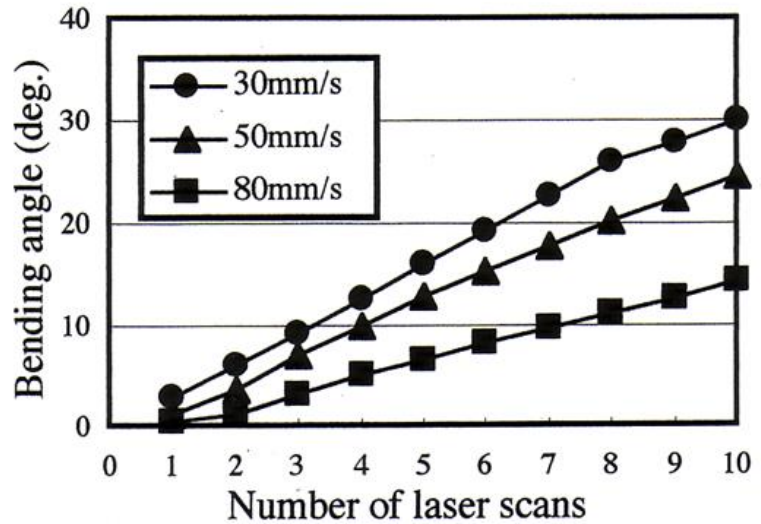


Fig. Relationship between number of laser scans and bending angle (SUS304 1.0mm thickness)

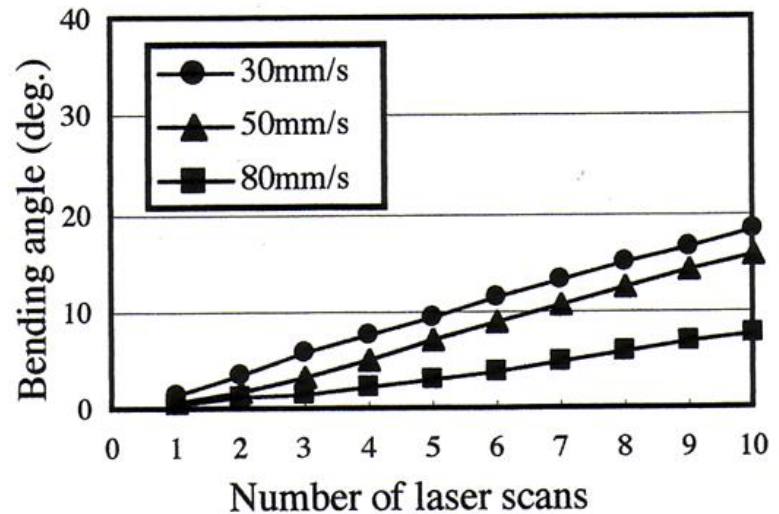


Fig. Relationship between number of laser scans and bending angle (SUS410 1.0mm thickness)

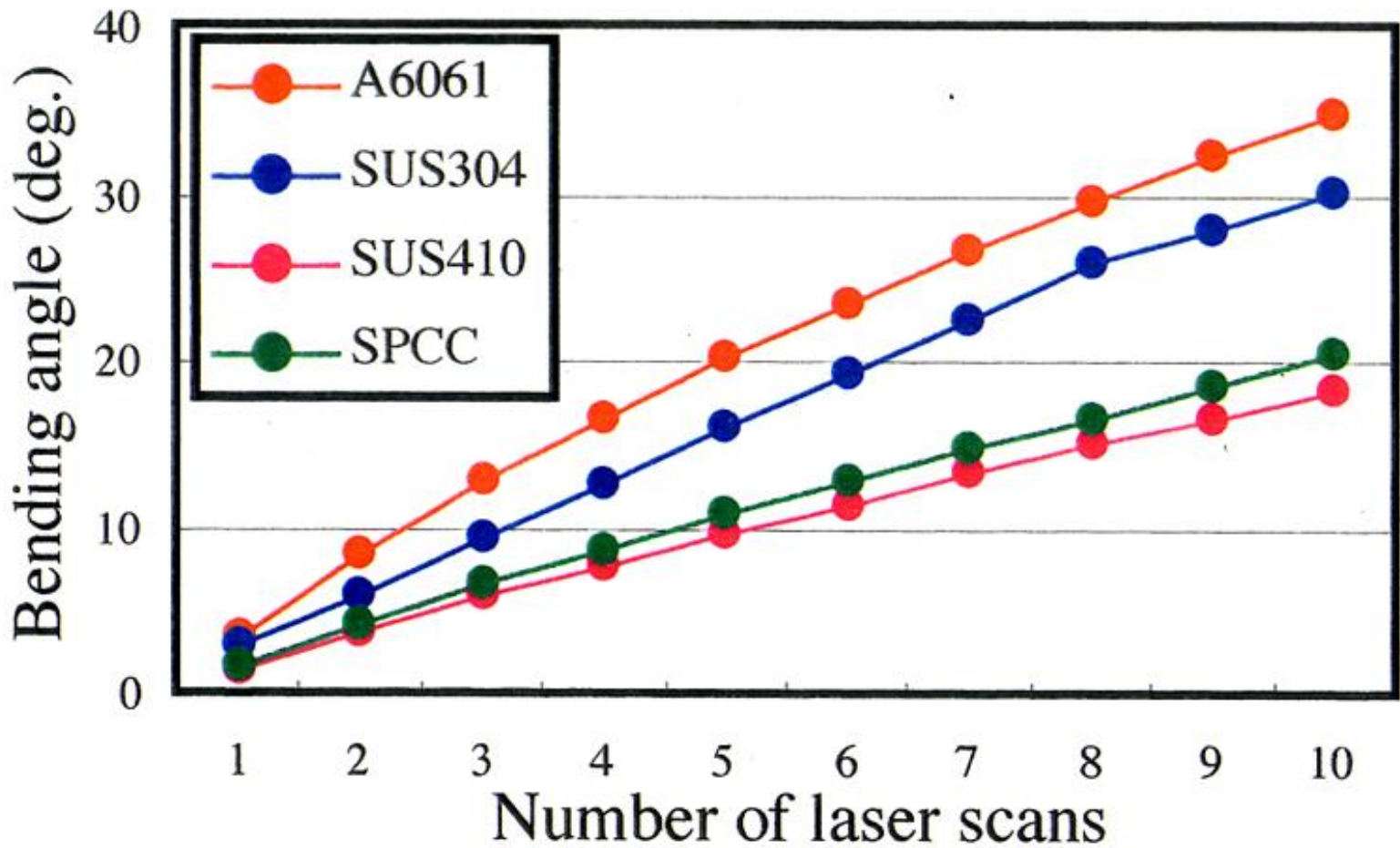
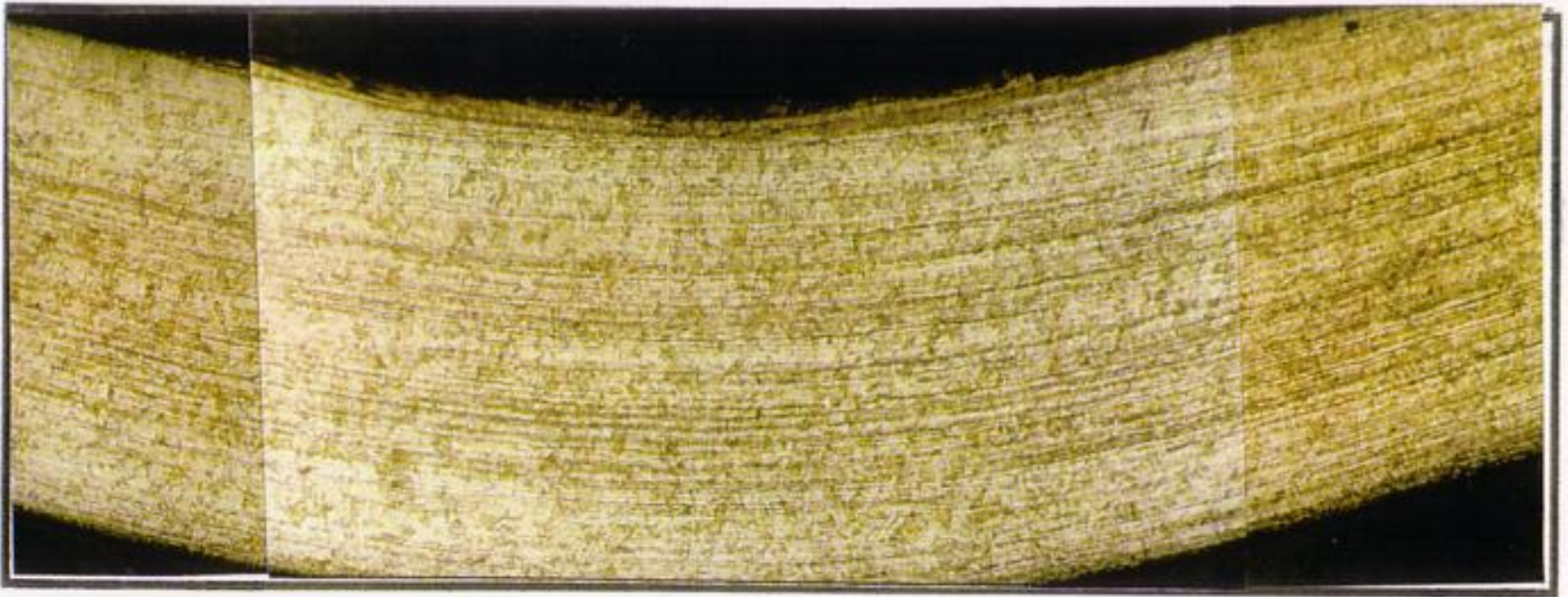


Fig. Bending angles of various materials with number of laser scans (1.0mm thickness)





Laser power 310W  
Spot diameter 3.9mm  
Table speed 30mm/s  
10pass  
Thickness 1.0mm

0.5mm

Fig.4-8(a) Cross section of SUS304 (1.0mm thickness)





Laser power 310W  
Spot diameter 3.9mm  
Table speed 30mm/s  
10pass  
Thickness 1.0mm

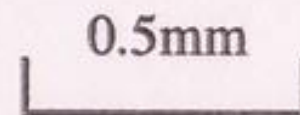


Fig.4-8(c) Cross section of SPCC (1.0mm thickness)



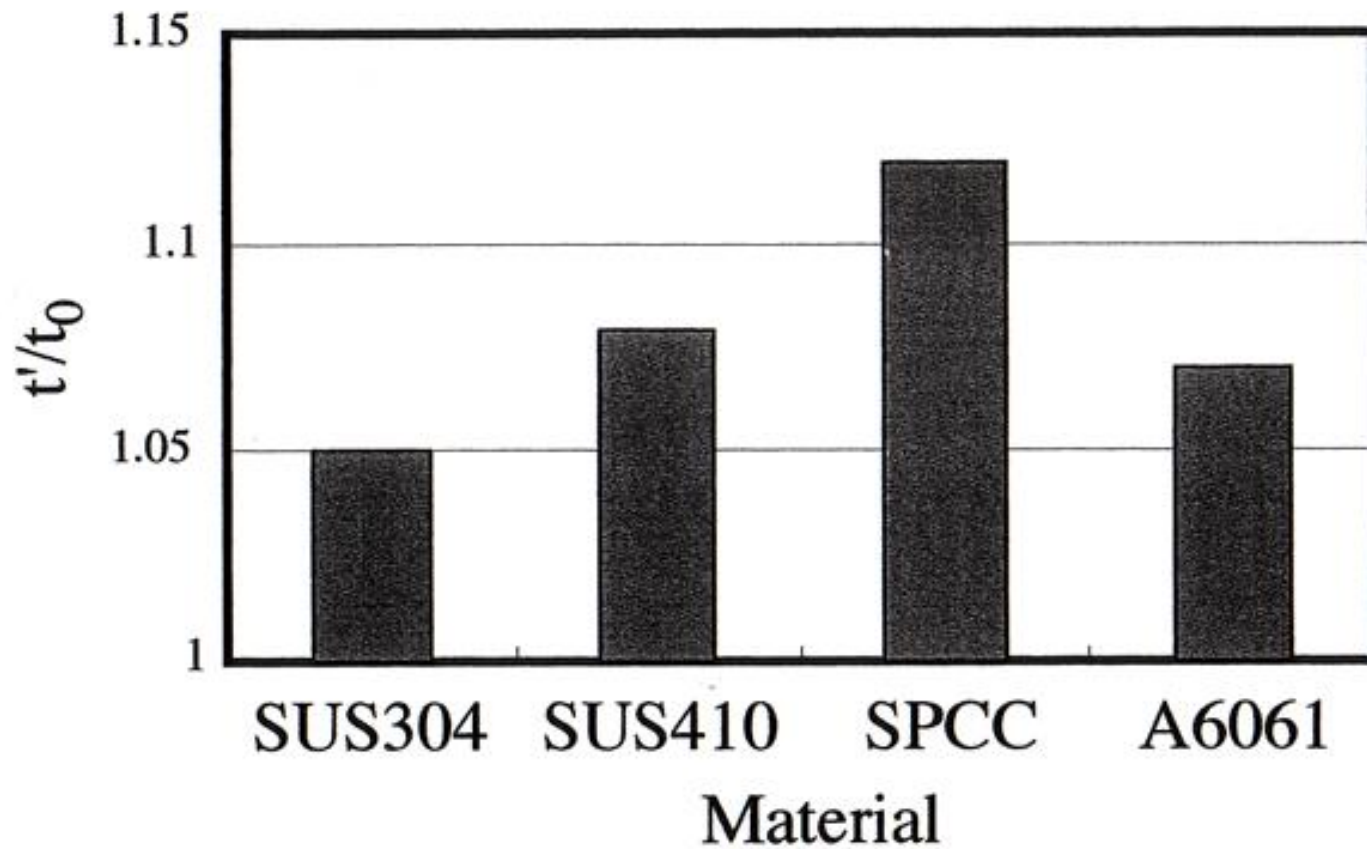


Fig. Surface expansion in each materials after 10 irradiations

# Considering material properties

Table Physical properties of materials used

Material	Specific heat ( $10^6\text{J/m}^3/\text{K}$ )	Thermal conductivity ( $\text{J/m/s/K}$ )	Coefficient of linear expansion ( $10^{-6}/^\circ\text{C}$ )	Thermal diffusivity ( $\text{m}^2/\text{s}$ )	Young's modulus ( $\text{kN/mm}^2$ )
SUS304	3.98	16.3	18.7	$4.1 \times 10^{-6}$	19.7
SUS410	3.57	24.9	11.7	$6.97 \times 10^{-6}$	20.4
SPCC	3.95	46.9	11.6	$11.9 \times 10^{-6}$	21.0
A6061	2.42	167	23.6	$69 \times 10^{-6}$	7.04

# Calculation for thermal distribution of metal sheet

$$T = \frac{k_D}{4k(\pi k_D)^{3/2}} \int_0^{\infty} \frac{dt}{\sqrt{t^3}} \int_{-\infty}^{\infty} dx' \int_{-\infty}^{\infty} w(x', y') \exp\left[ -\frac{(x-x' + vt)^2 + (y-y')^2 + z^2}{4k_D t} \right]$$

$$w(x, y) = \frac{AW}{\pi ab} \exp\left[ -\frac{x^2}{a^2} - \frac{y^2}{b^2} \right]$$

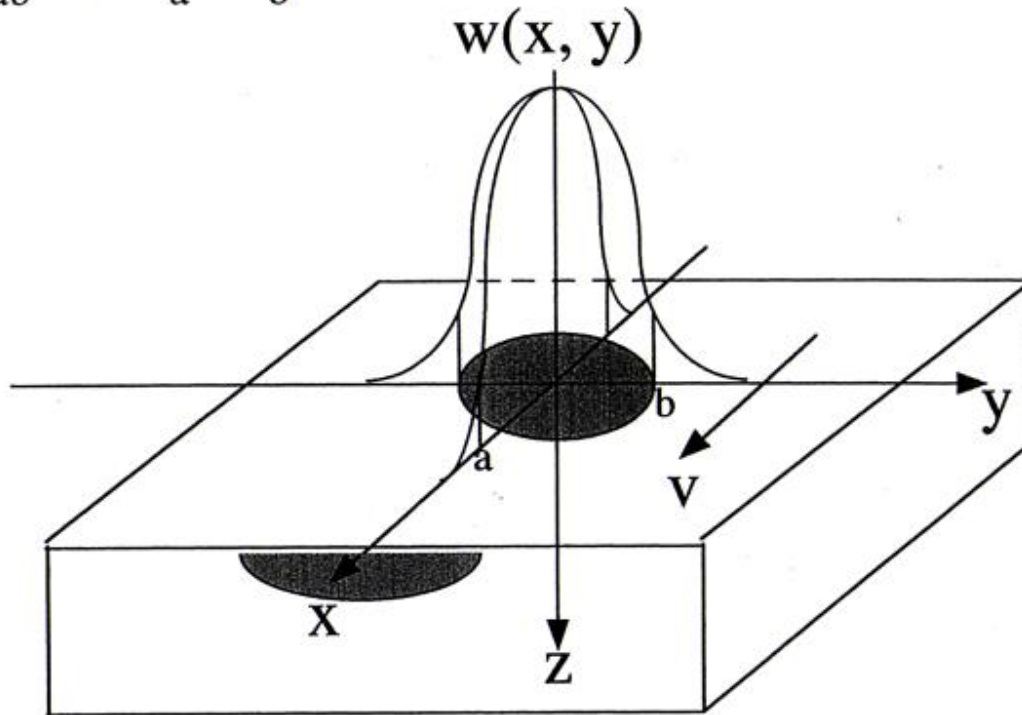


Fig. Gaussian heat source

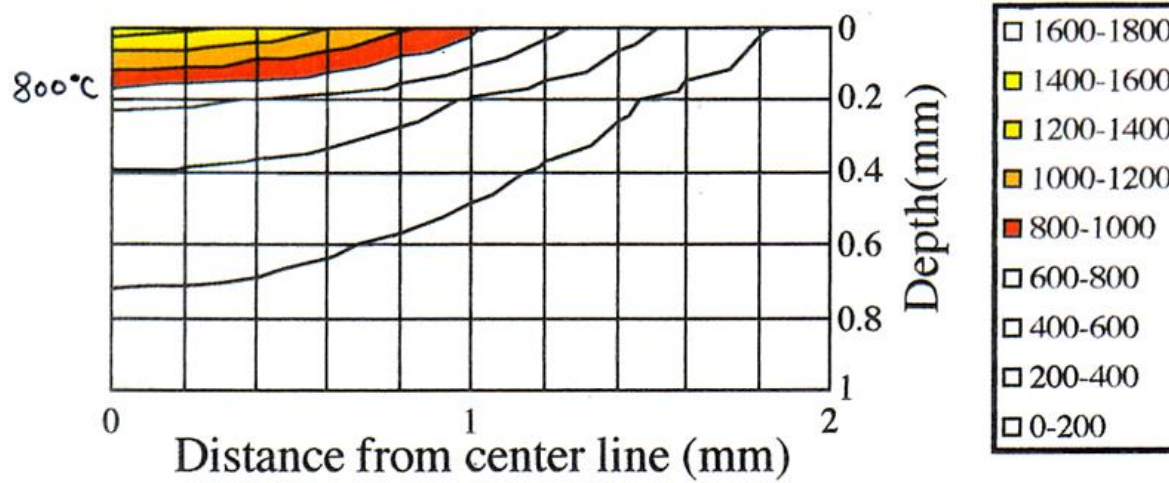


Fig. The isothermal lines of the peak temperature distribution (SPCC:thickness=1.0mm)

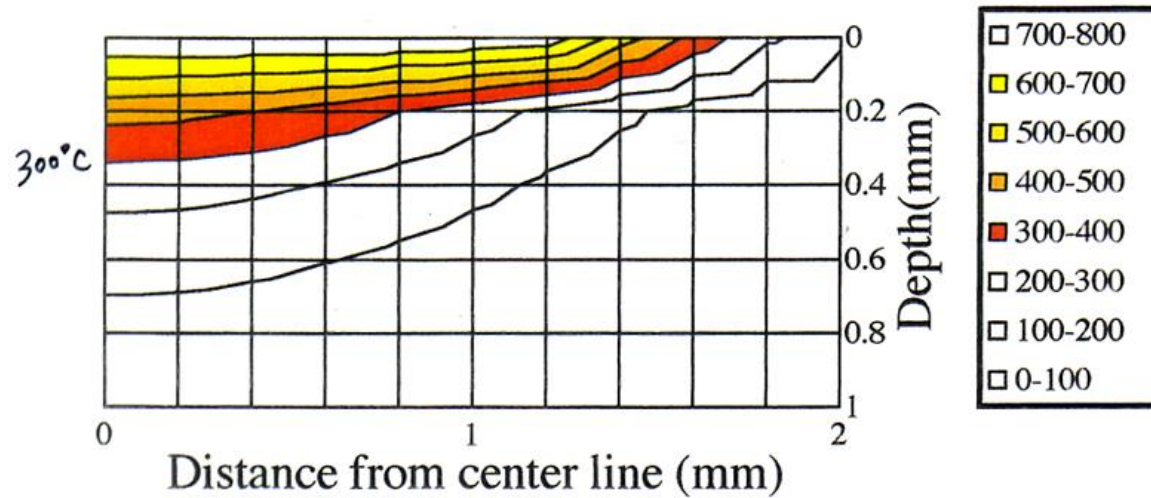


Fig. The isothermal lines of the peak temperature distribution (A6061:thickness=1.0mm)



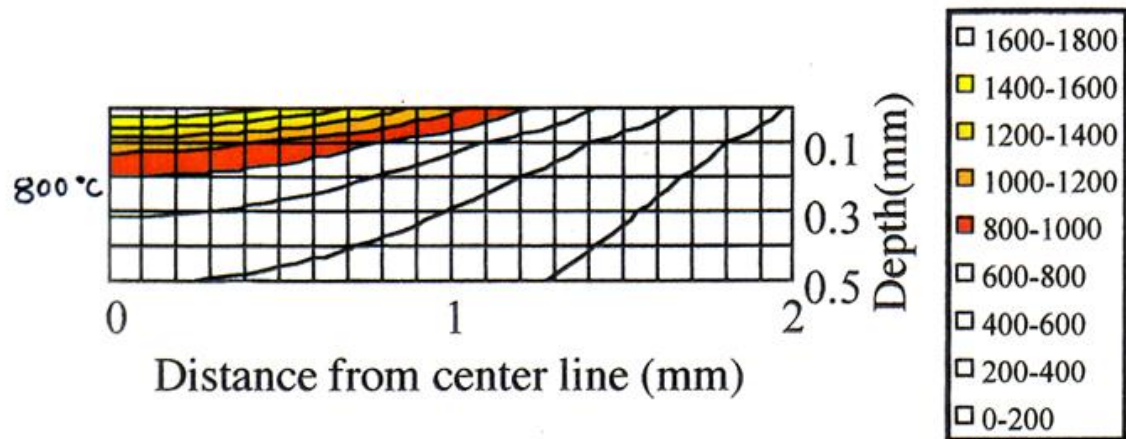


Fig. (a) The isothermal lines of the peak temperature distribution (SUS410 0.5mm thickness)

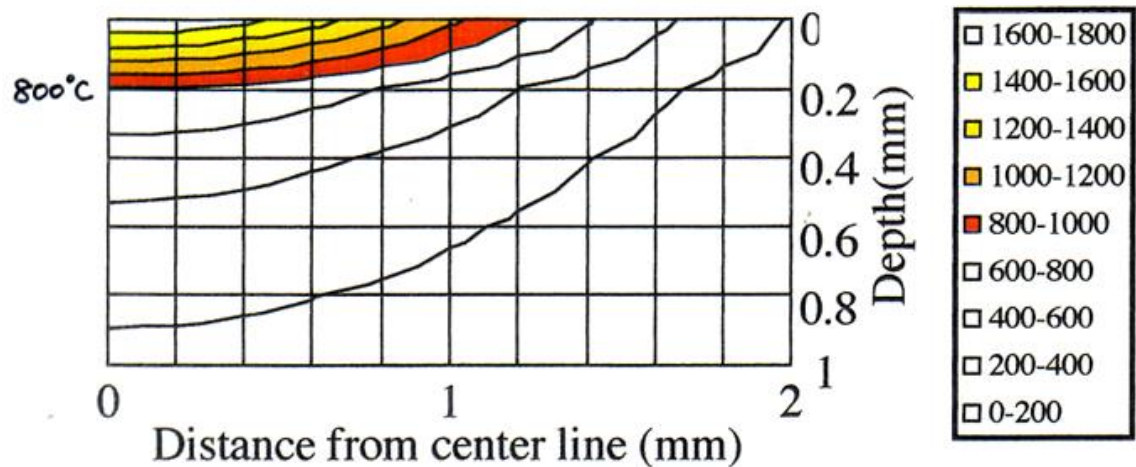
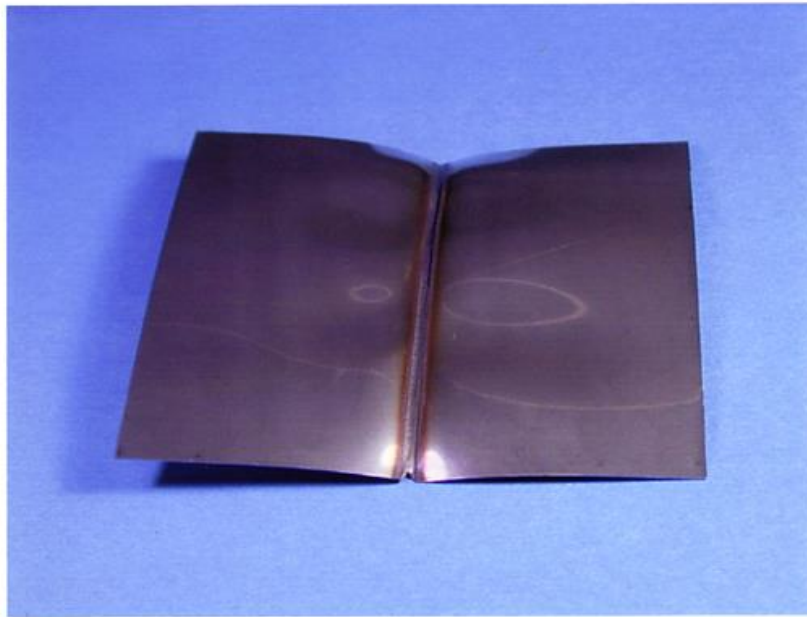
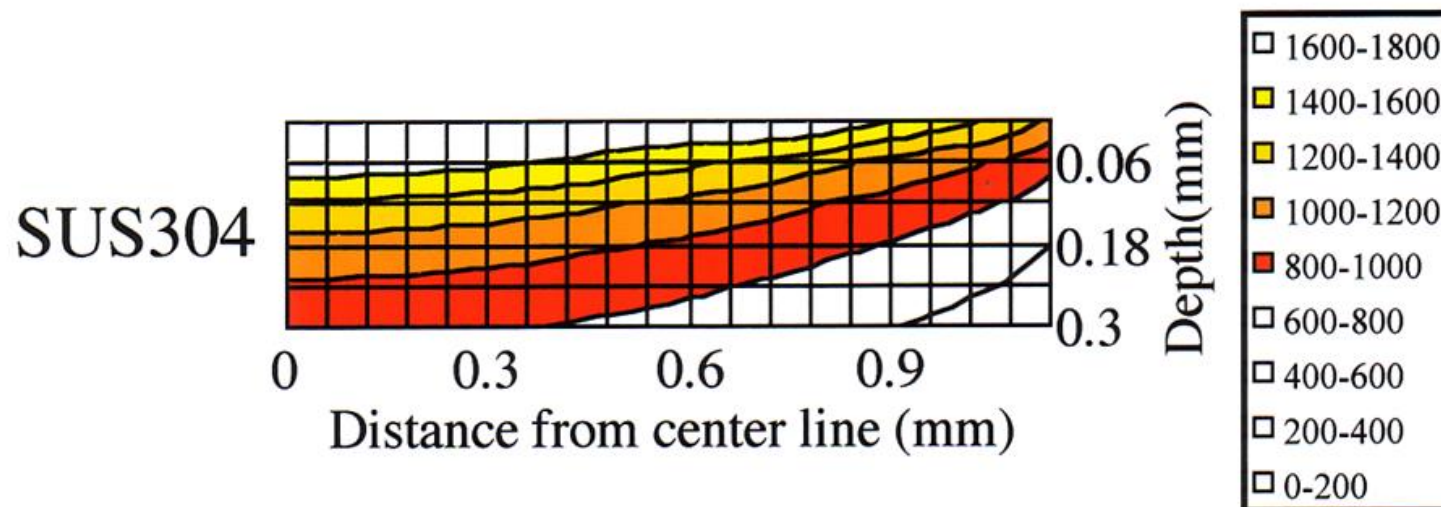


Fig. (b) The isothermal lines of the peak temperature distribution (SUS410 1.0mm thickness)

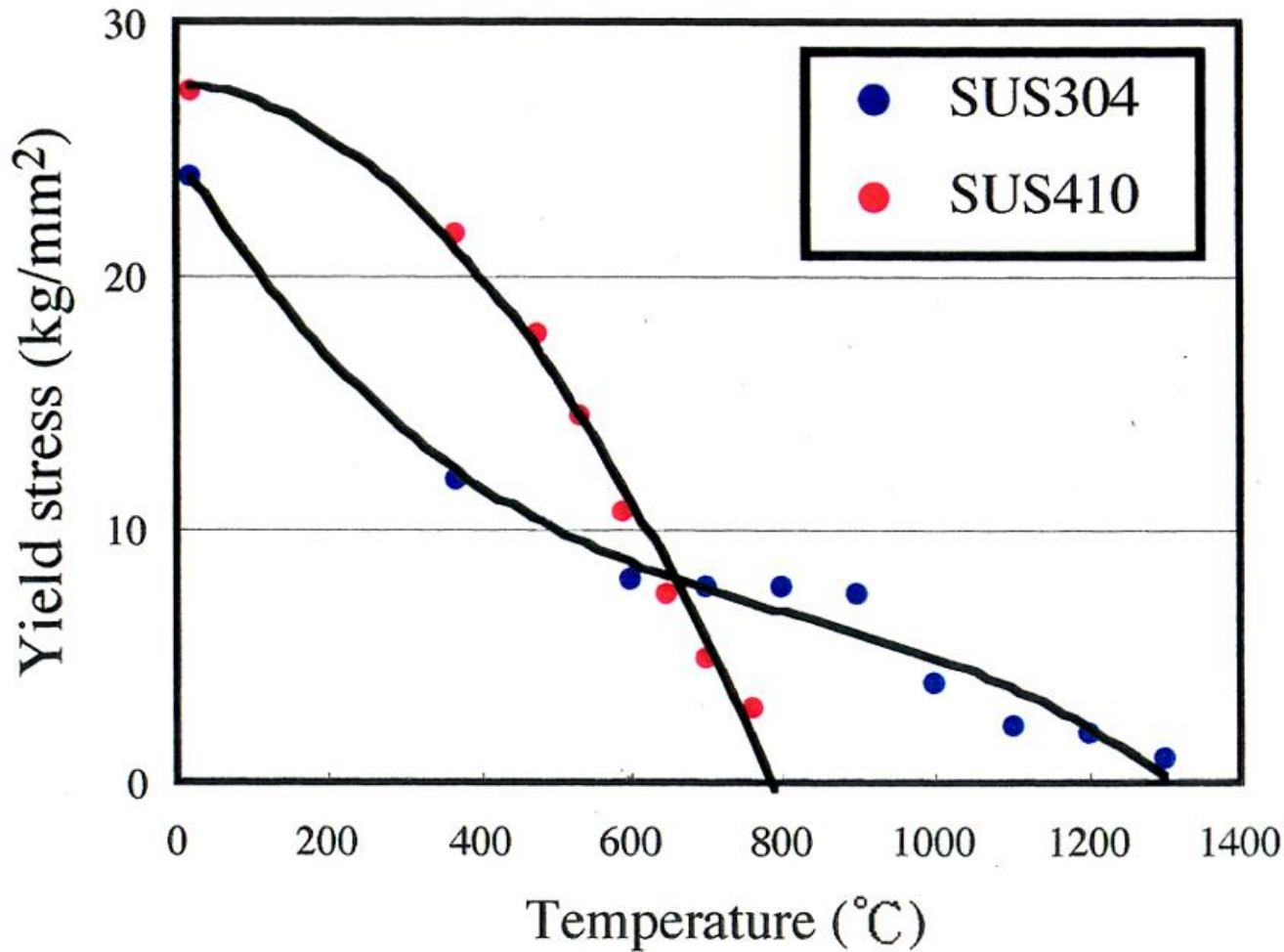


$t=0.3\text{mm}$

Fig. Appearance of deformed SUS304 plate(10pass)



# Temperature dependence of yield stress



Relationship between yield stress and temperature in stainless steels



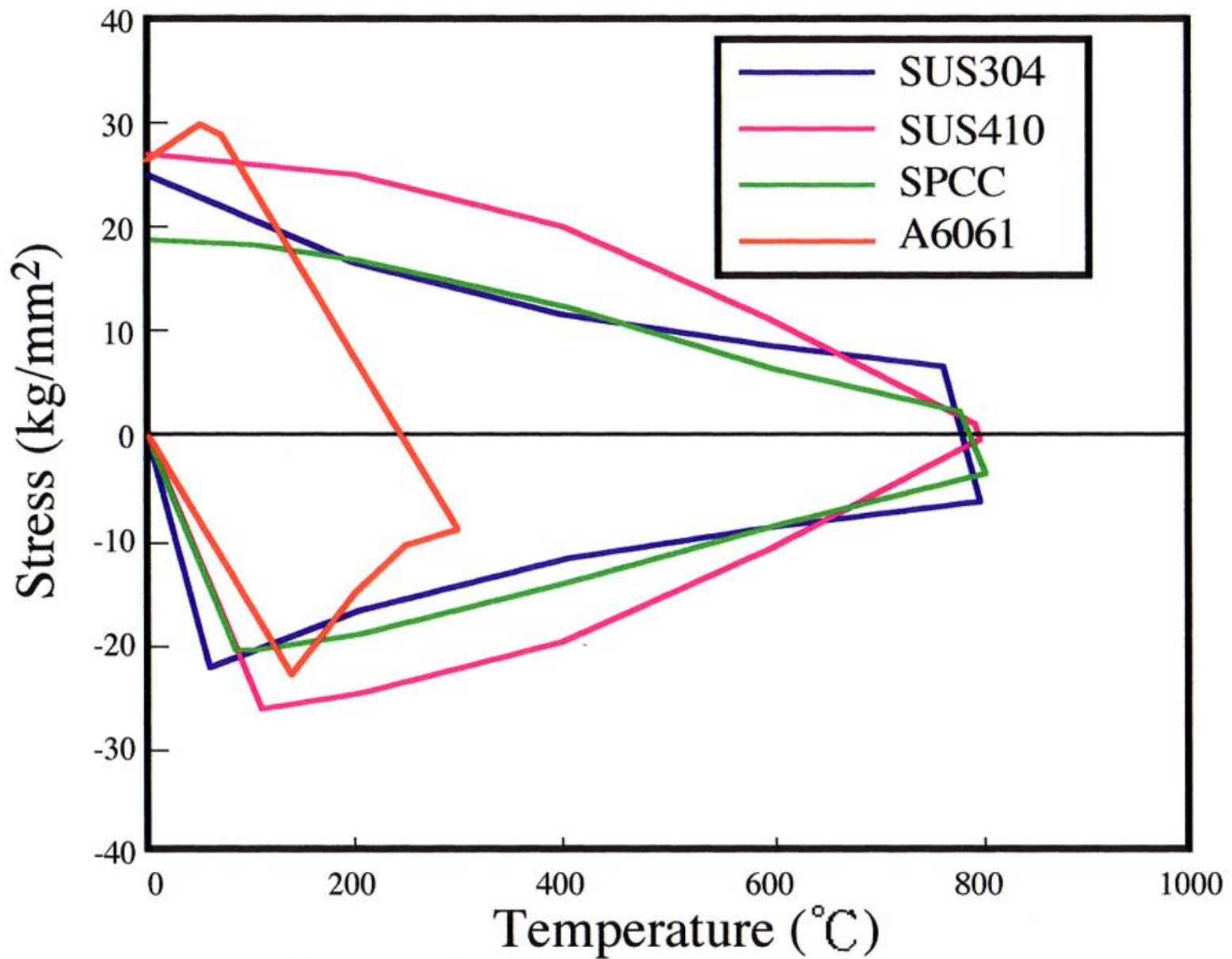


Fig. Thermal stress developed in stainless steel during single thermal cycle

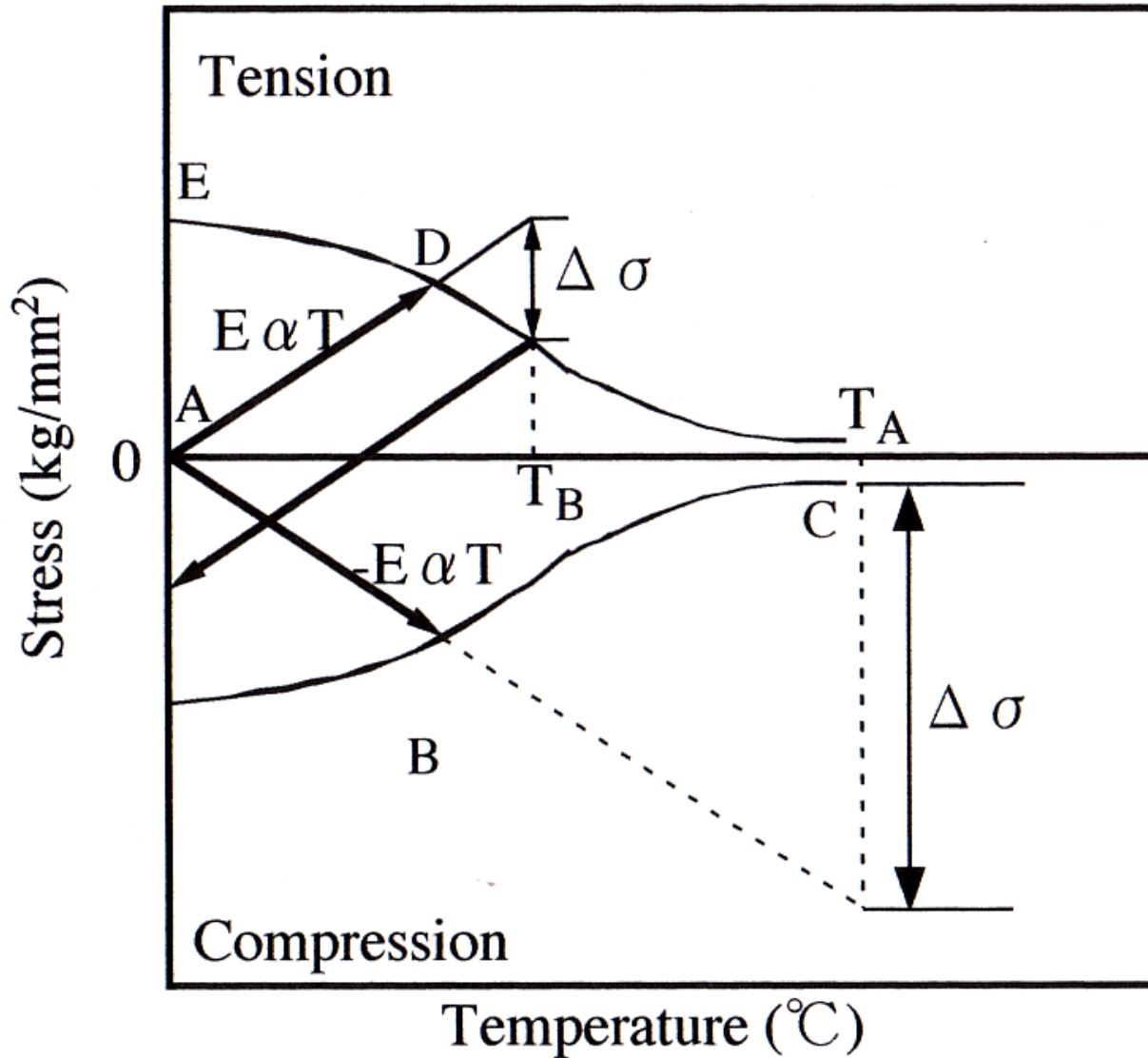
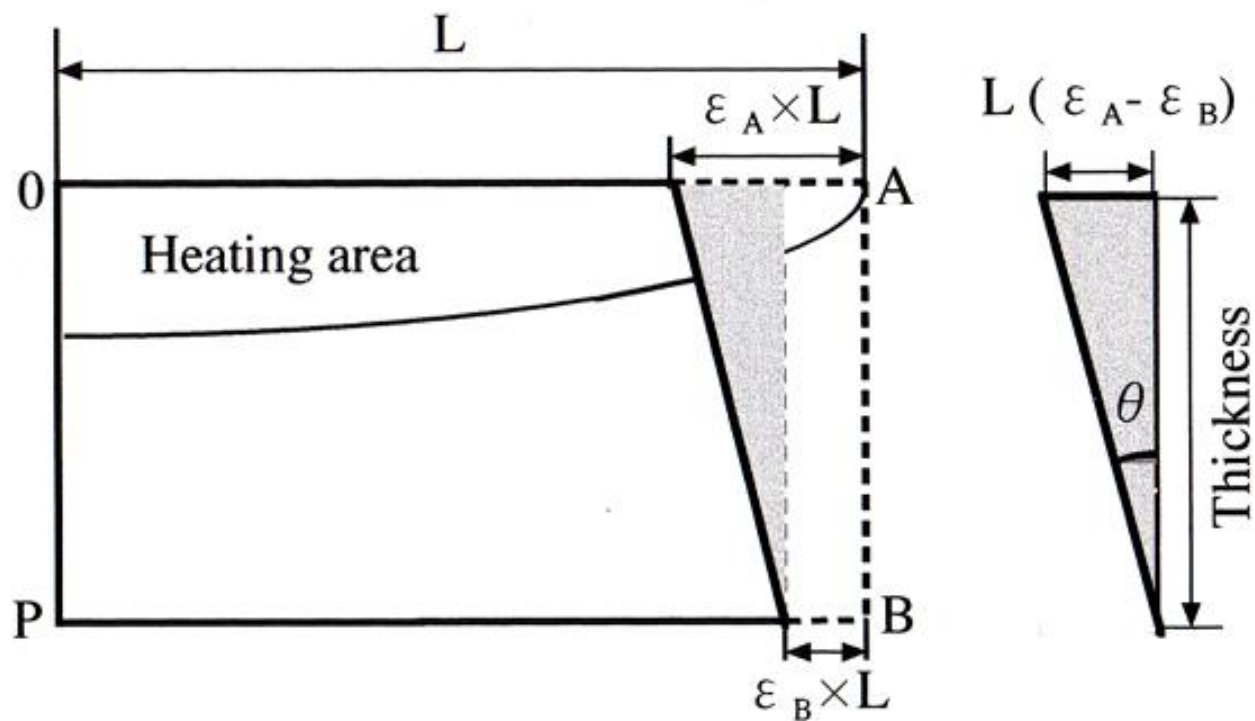
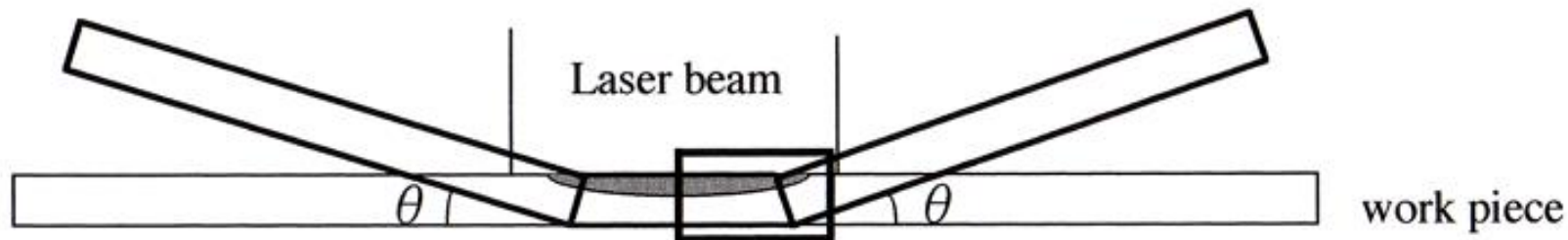


Fig. (a) The typical thermal stress during single thermal cycle

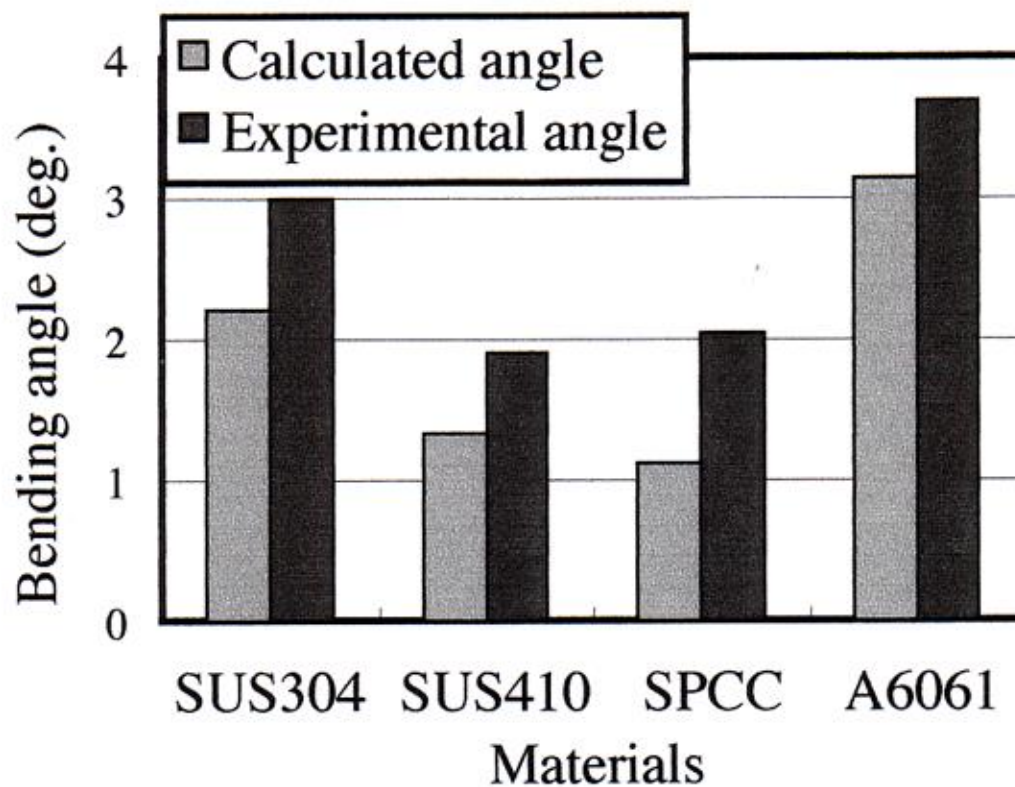


$$\text{Bending angle} = 2 \tan^{-1} \left( \frac{L(\epsilon_A - \epsilon_B)}{\text{Thickness}} \right)$$

Fig. Method of calculation

**Table** The comparison of bending angle in material used

Materials	SUS304	SUS410	SPCC	A6061
Thickness (mm)	1.0	1.0	1.0	1.0
Strain :top $\varepsilon_A$	$1.46 \times 10^{-2}$	$9.36 \times 10^{-3}$	$9.16 \times 10^{-3}$	$5.7 \times 10^{-3}$
Strain :bottom $\varepsilon_B$	$1.44 \times 10^{-3}$	$2.11 \times 10^{-4}$	$2.21 \times 10^{-3}$	$1.71 \times 10^{-3}$
Calculated angle (deg.)	2.22	1.31	1.12	3.15
Experimental angle (deg.)	3.01	1.93	2.04	3.7





**Thank you for your kind  
attention**

