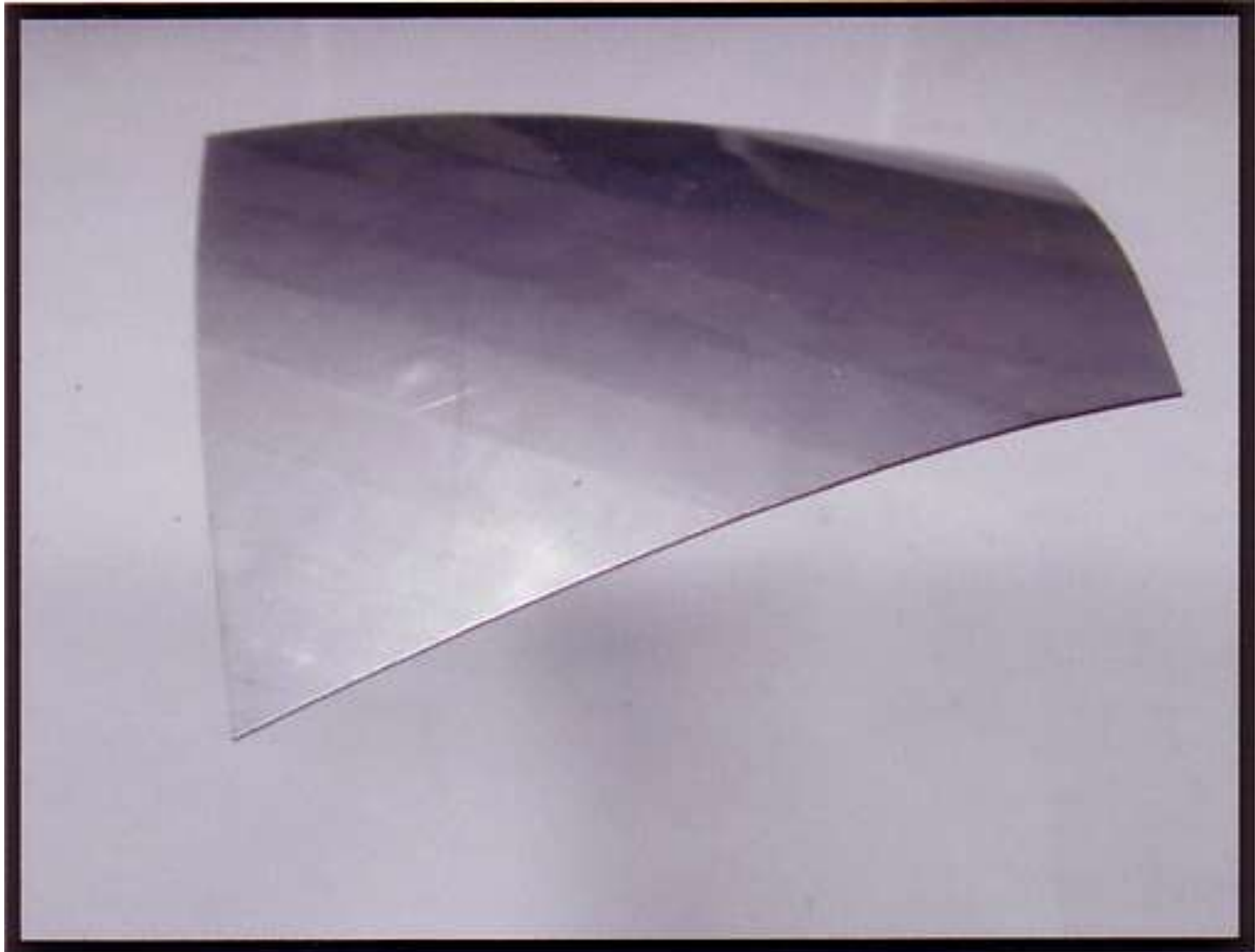


Laser Forming of metallic materials

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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

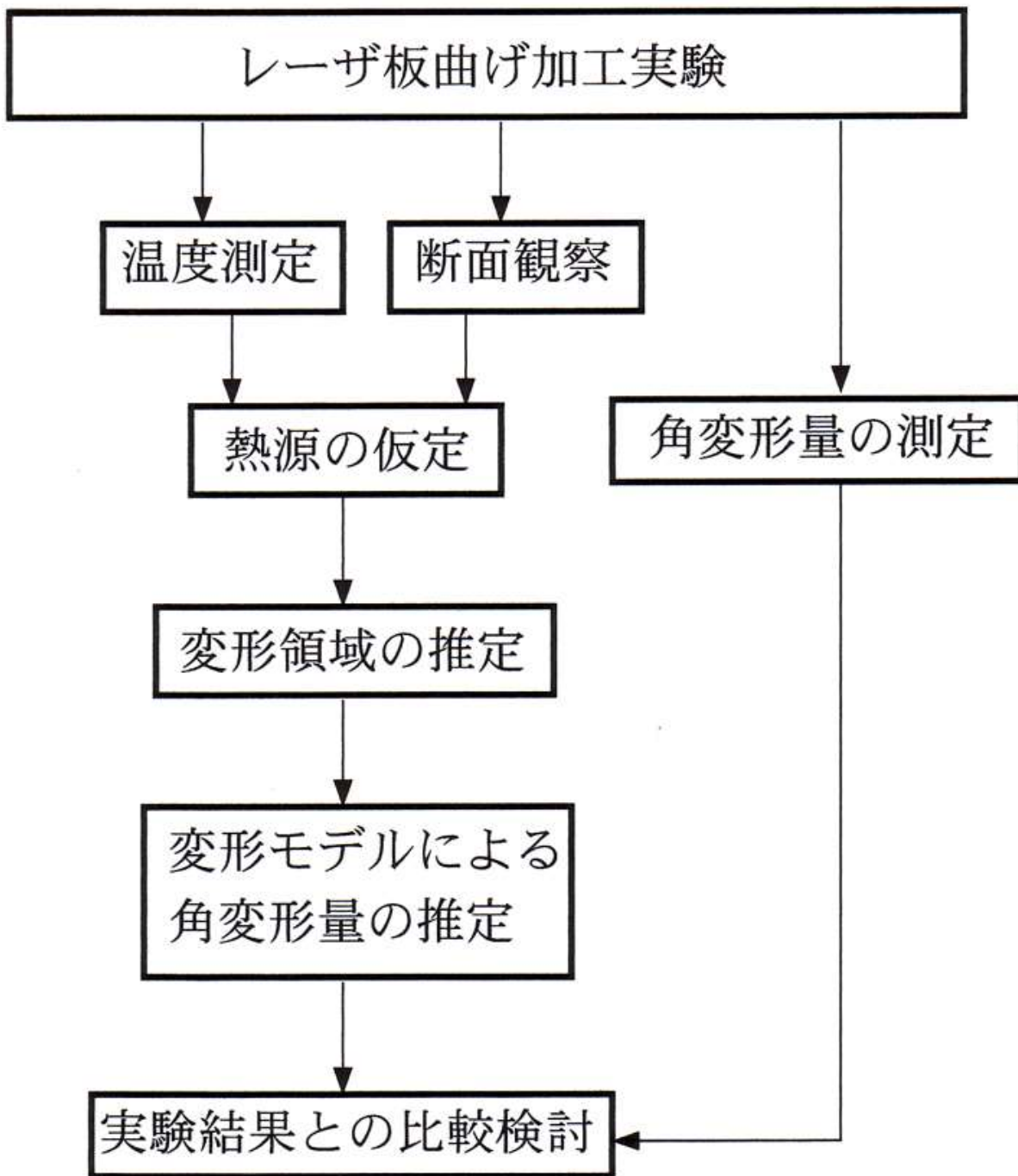
熱源の仮定

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

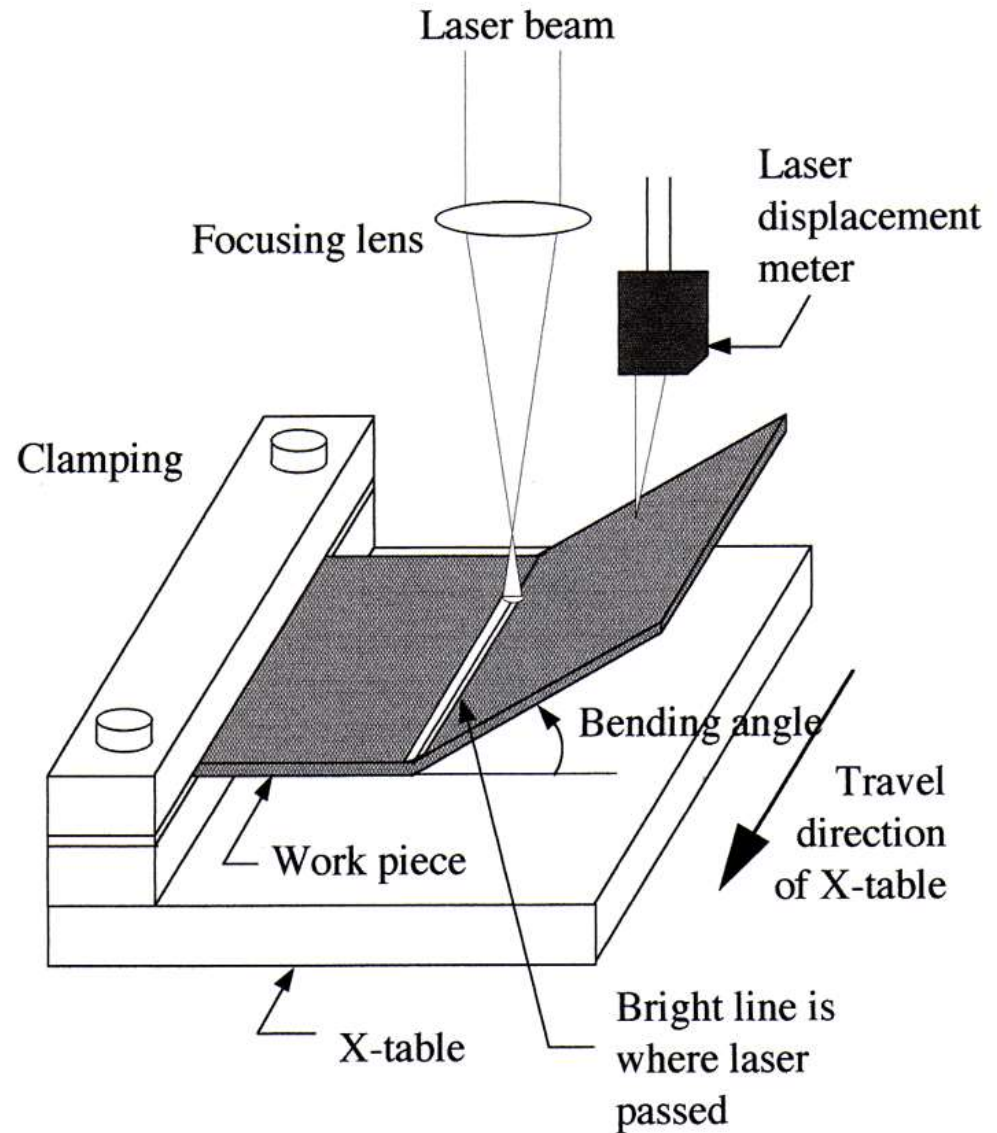


Fig. Schematic drawing of laser bending experiment

Laser heating condition

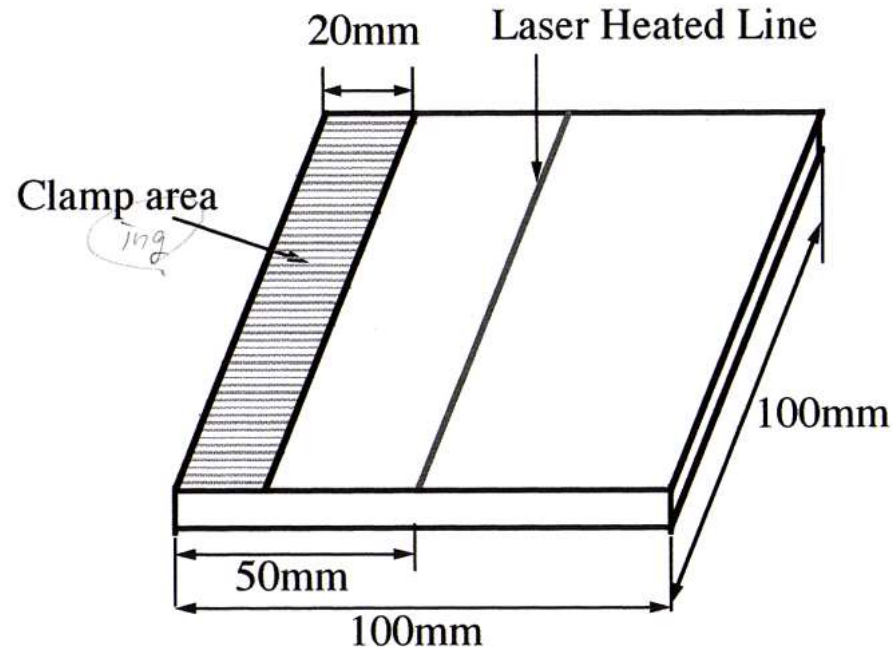


Fig. work piece

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

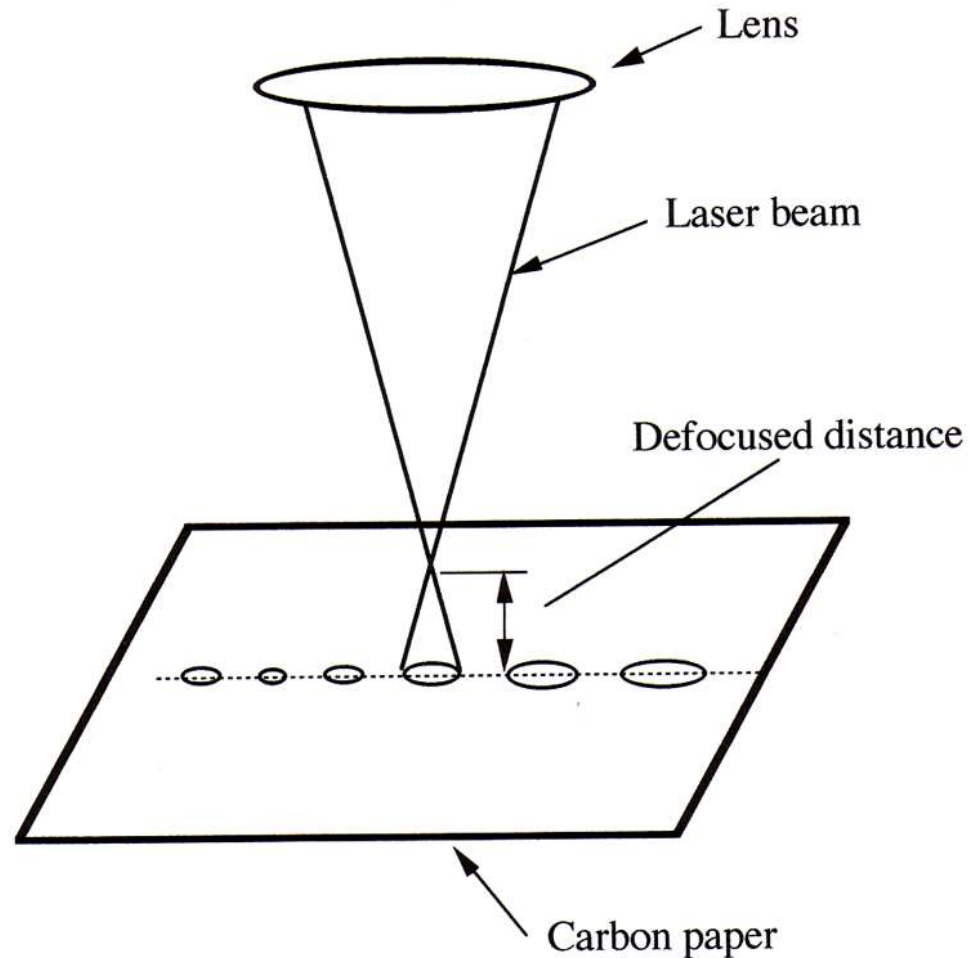


Fig. Diagram of determination of focusing distance with carbon paper

Measurement of thermal cycle

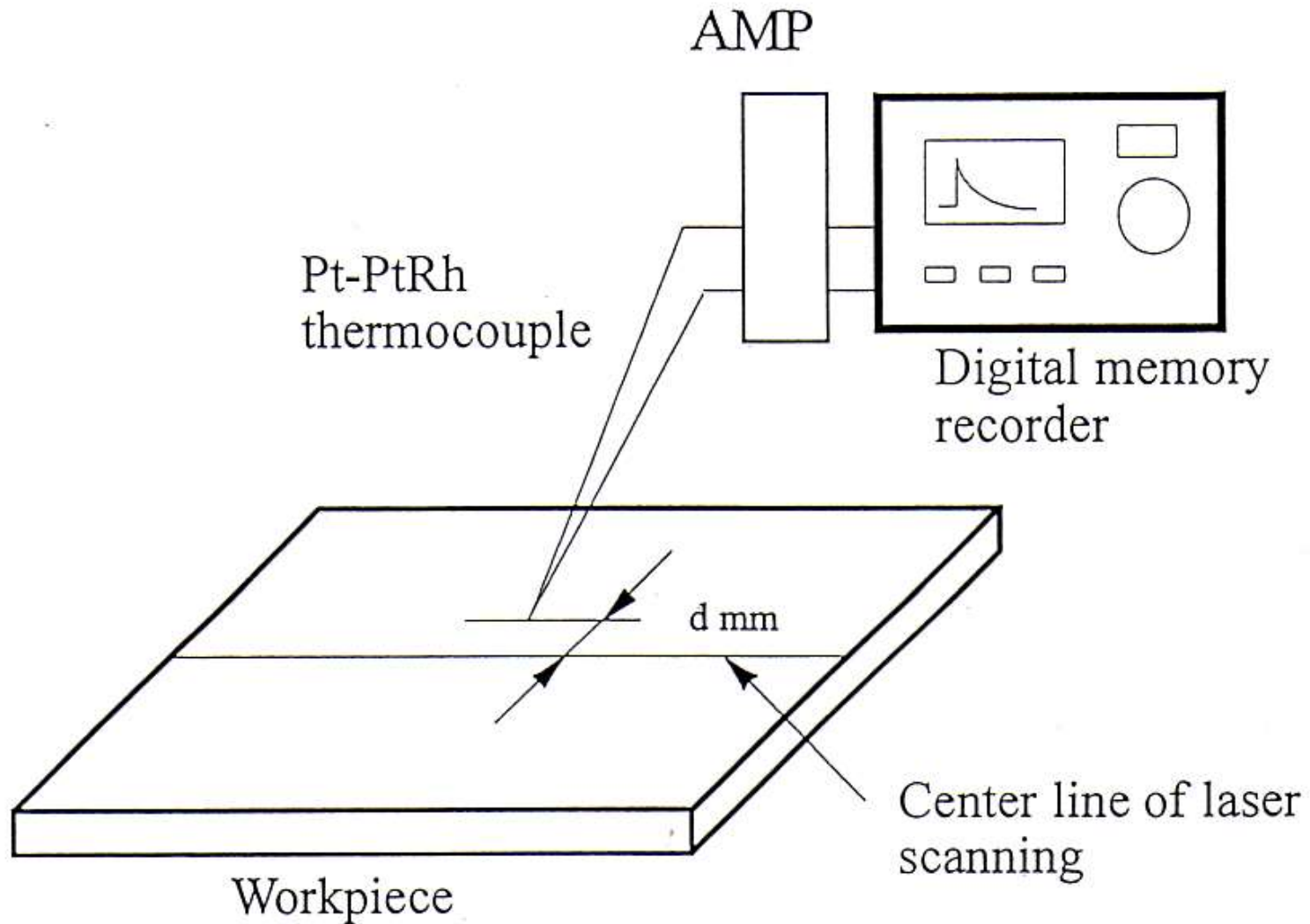


Table Chemical composition of stainless steels (mass%)

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

SUS304

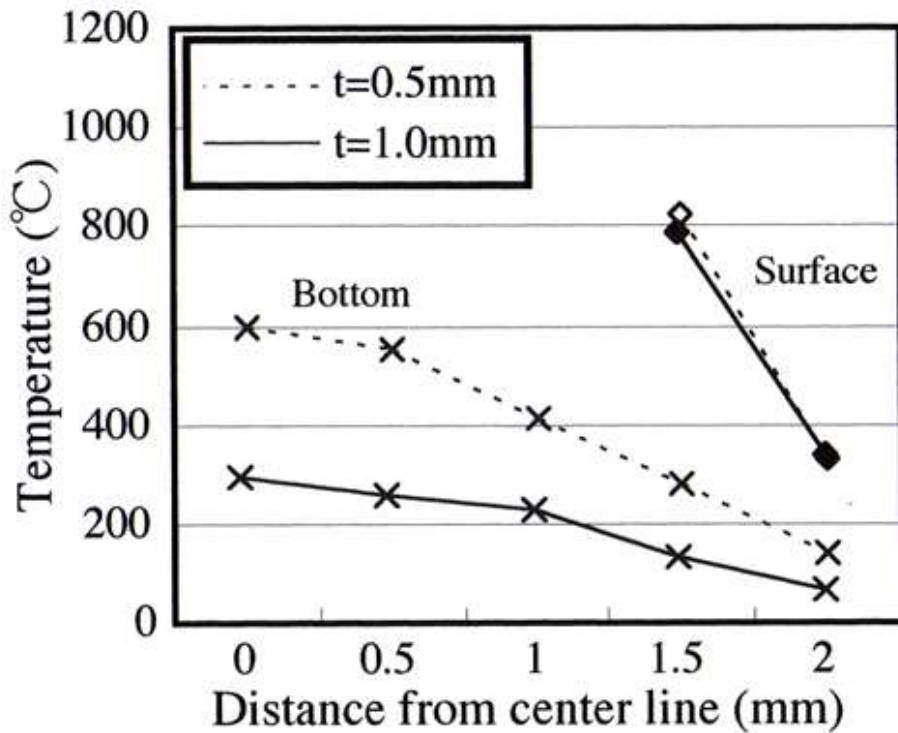


Fig. Relationship between temperature and distance from center line

SUS410

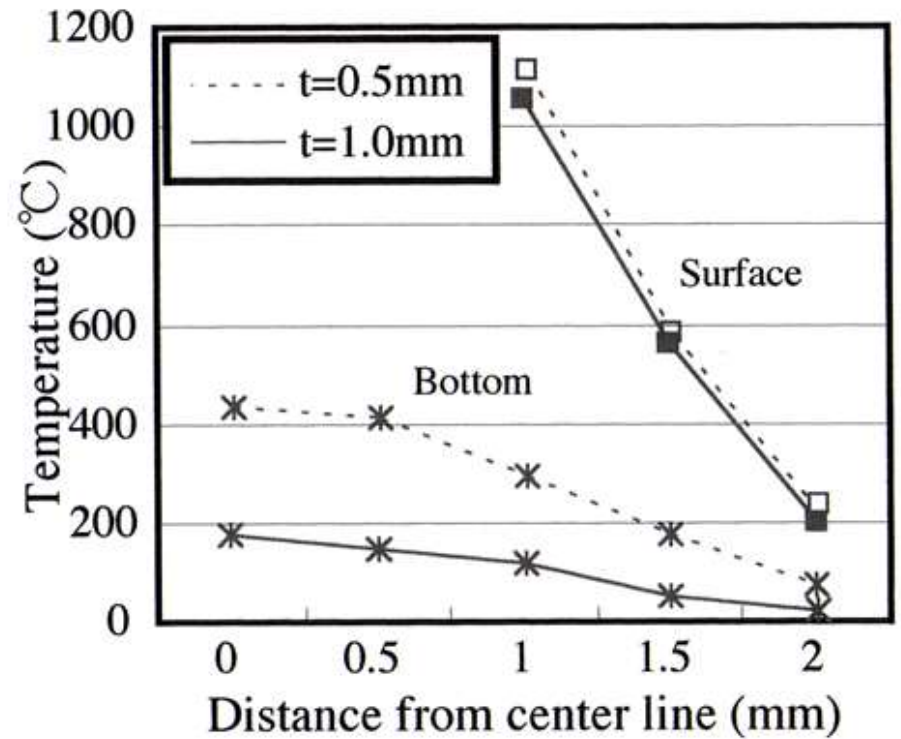


Fig. Relationship between temperature and distance from center line

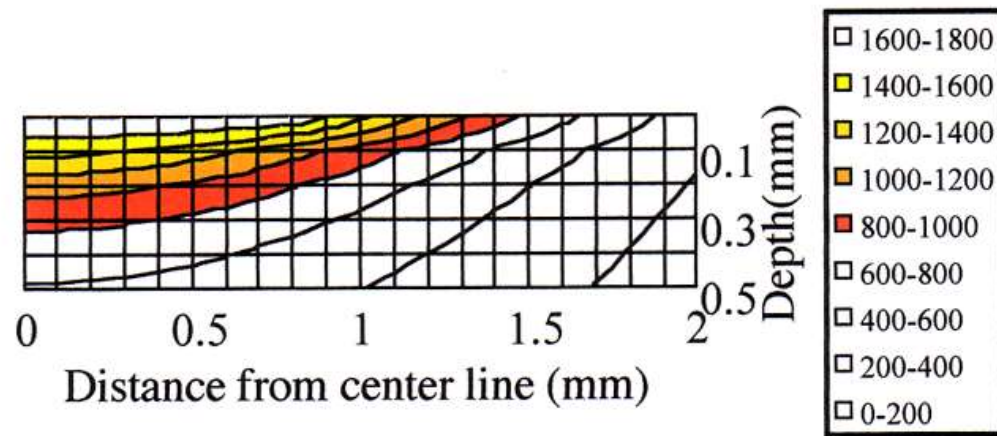


Fig. (a) The isothermal lines of the peak temperature distribution (SUS304 0.5mm thickness)

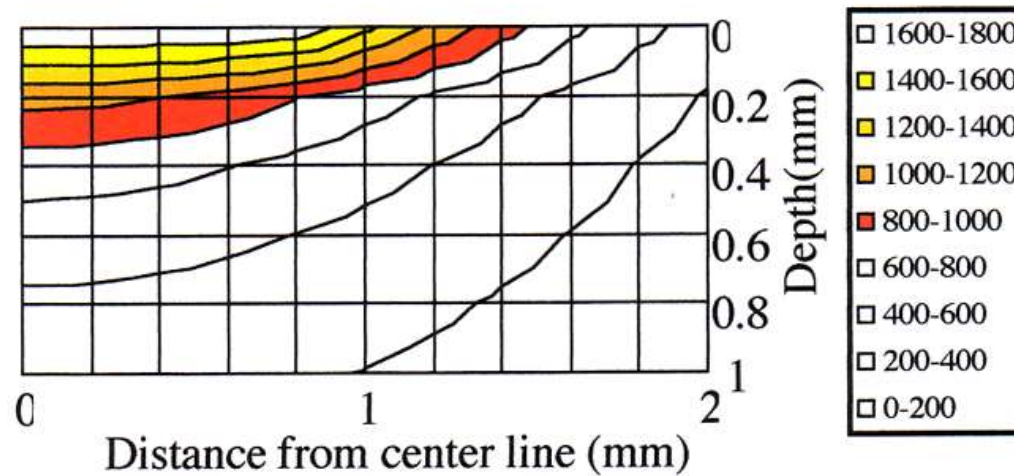


Fig. (b) The isothermal lines of the peak temperature distribution (SUS304 1.0mm thickness)

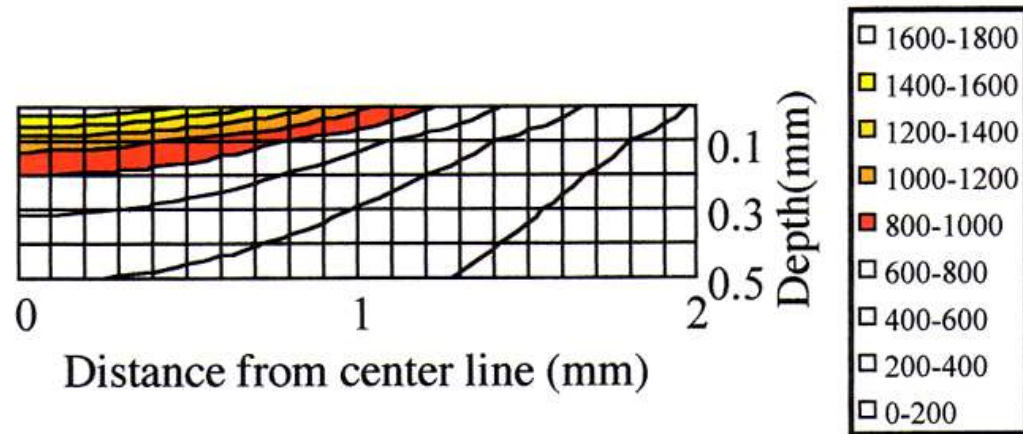


Fig. (a) The isothermal lines of the peak temperature distribution (SUS410 0.5mm thickness)

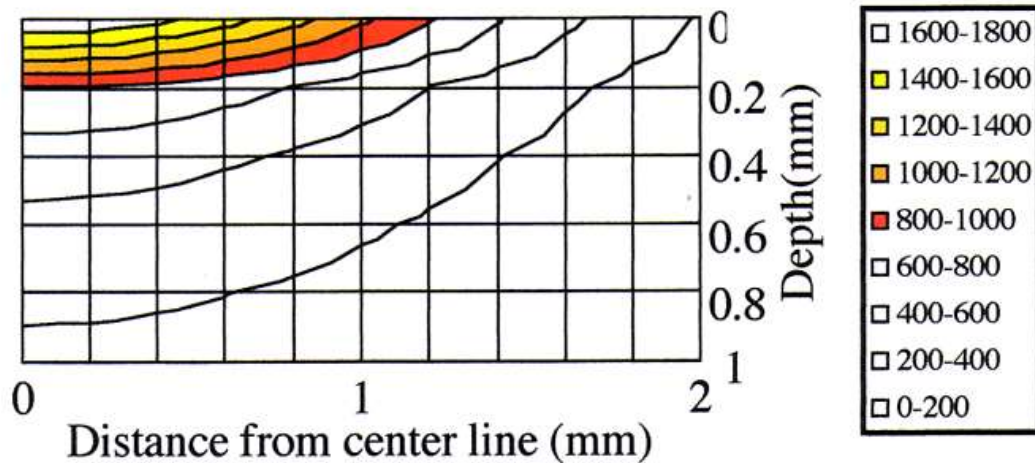
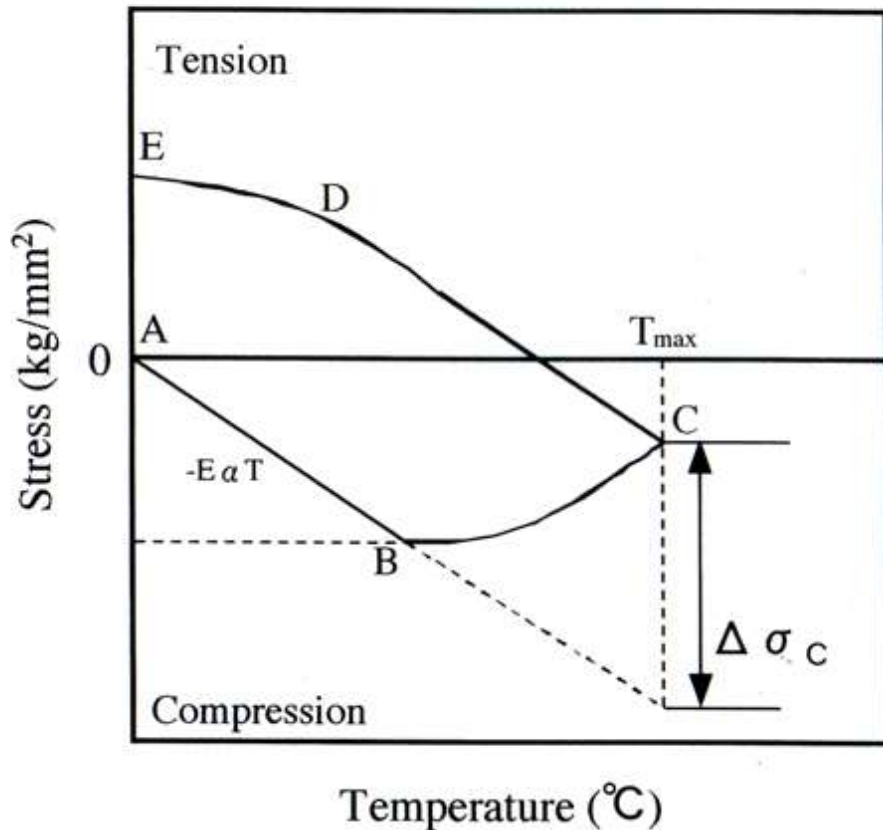
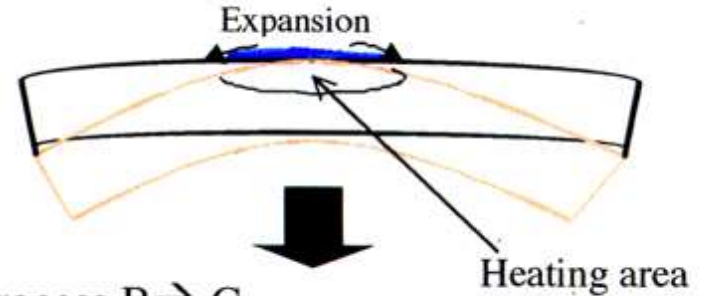


Fig. (b) The isothermal lines of the peak temperature distribution (SUS410 1.0mm thickness)

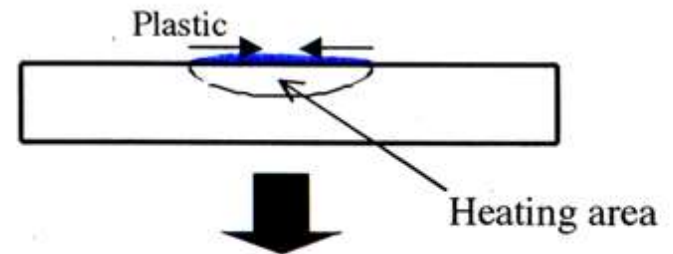
Deformation model by laser



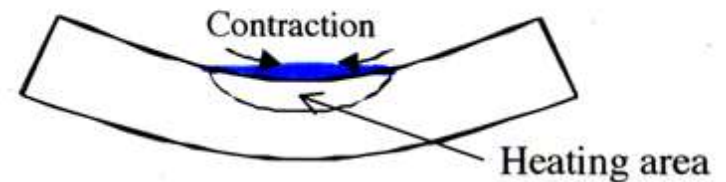
1) Process A \rightarrow B



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

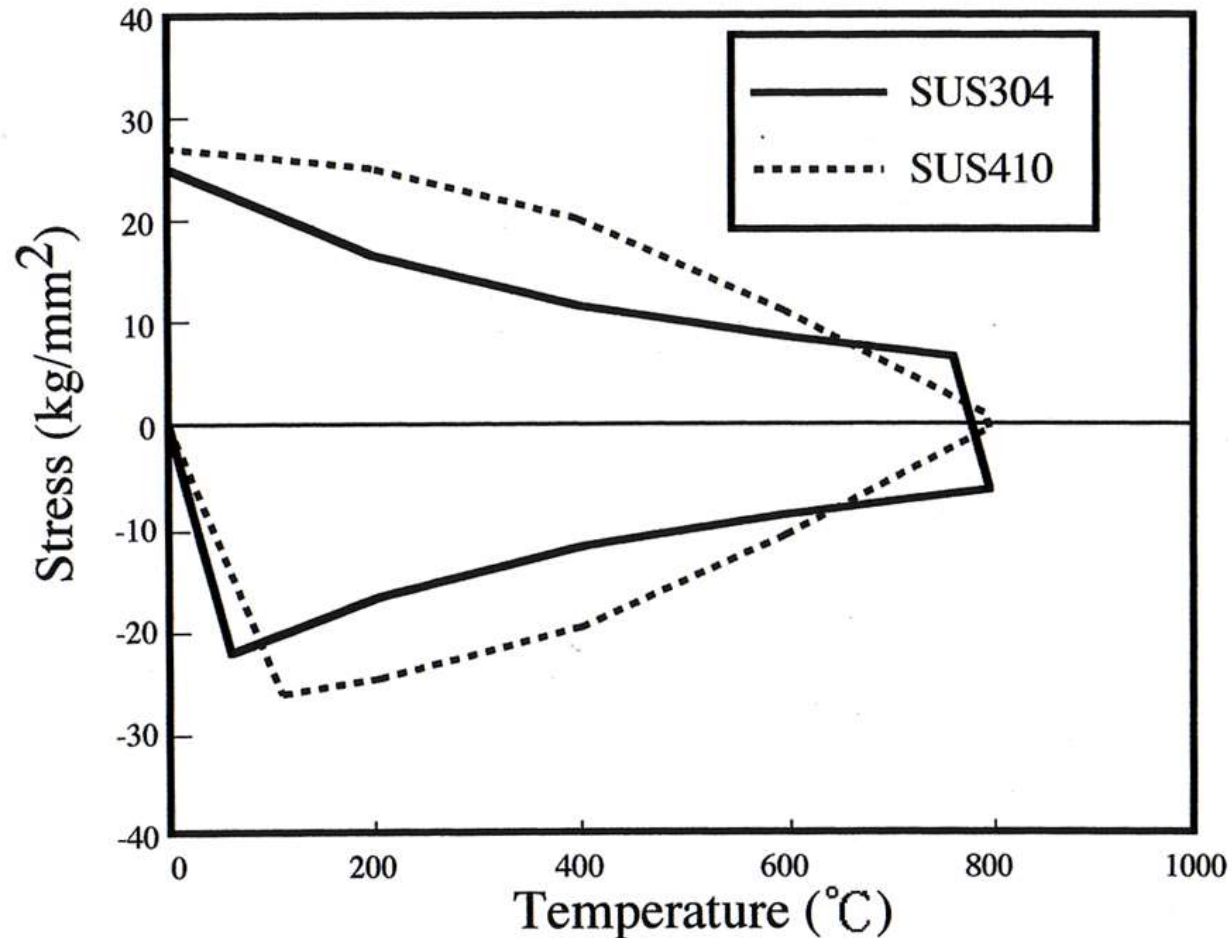
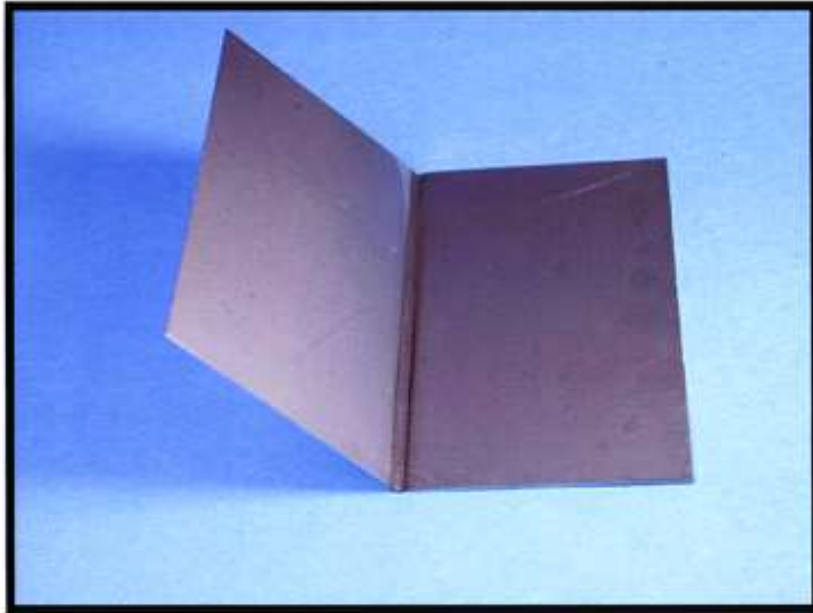


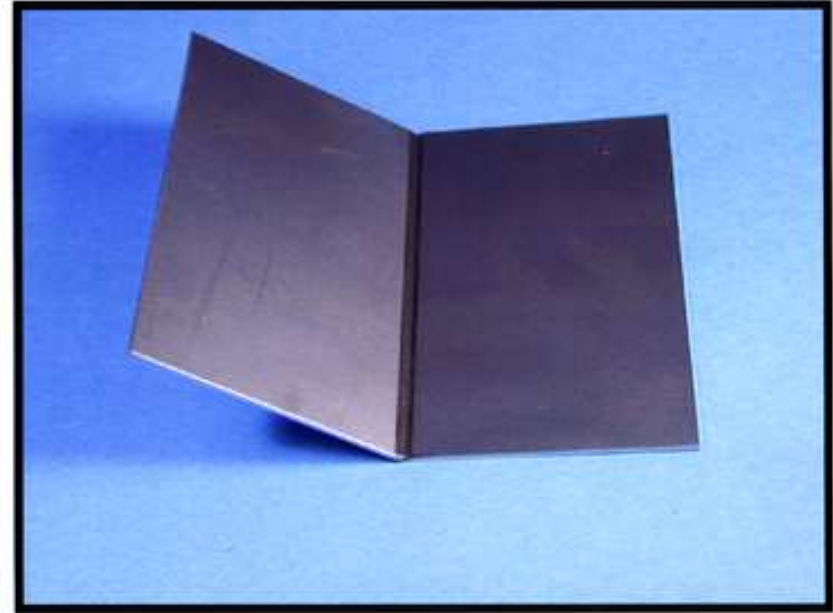
Fig. Thermal stress developed in stainless steel during single thermal cycle

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

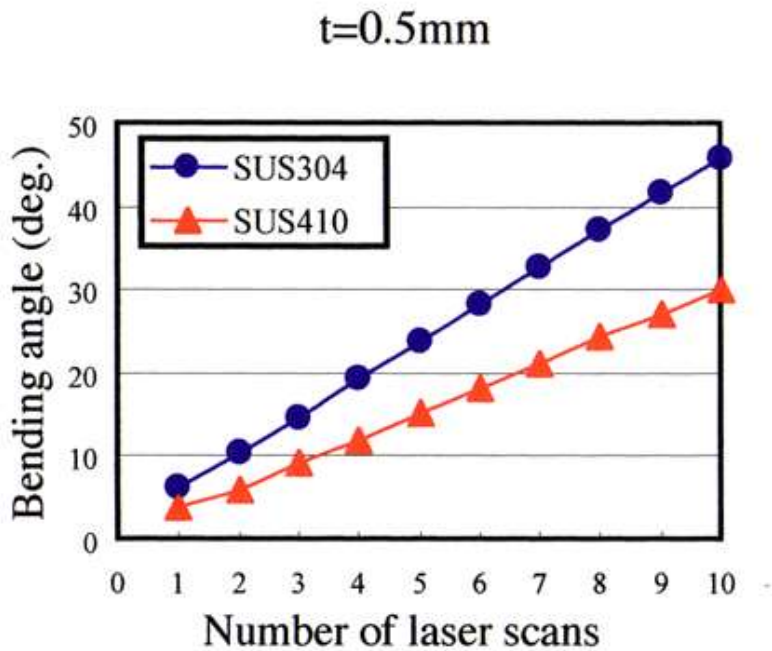


Fig.3-1 Relationship between number of laser scan and bending angle (0.5mm thickness)

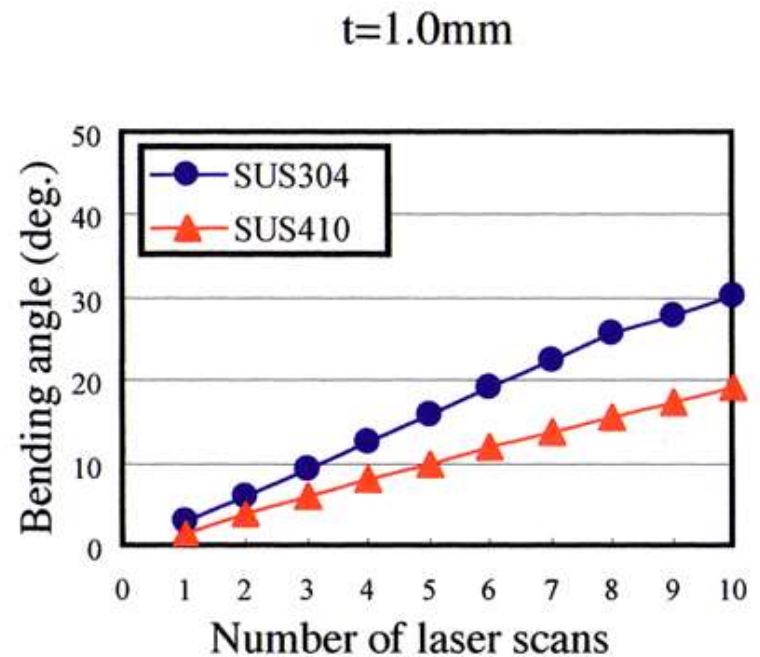
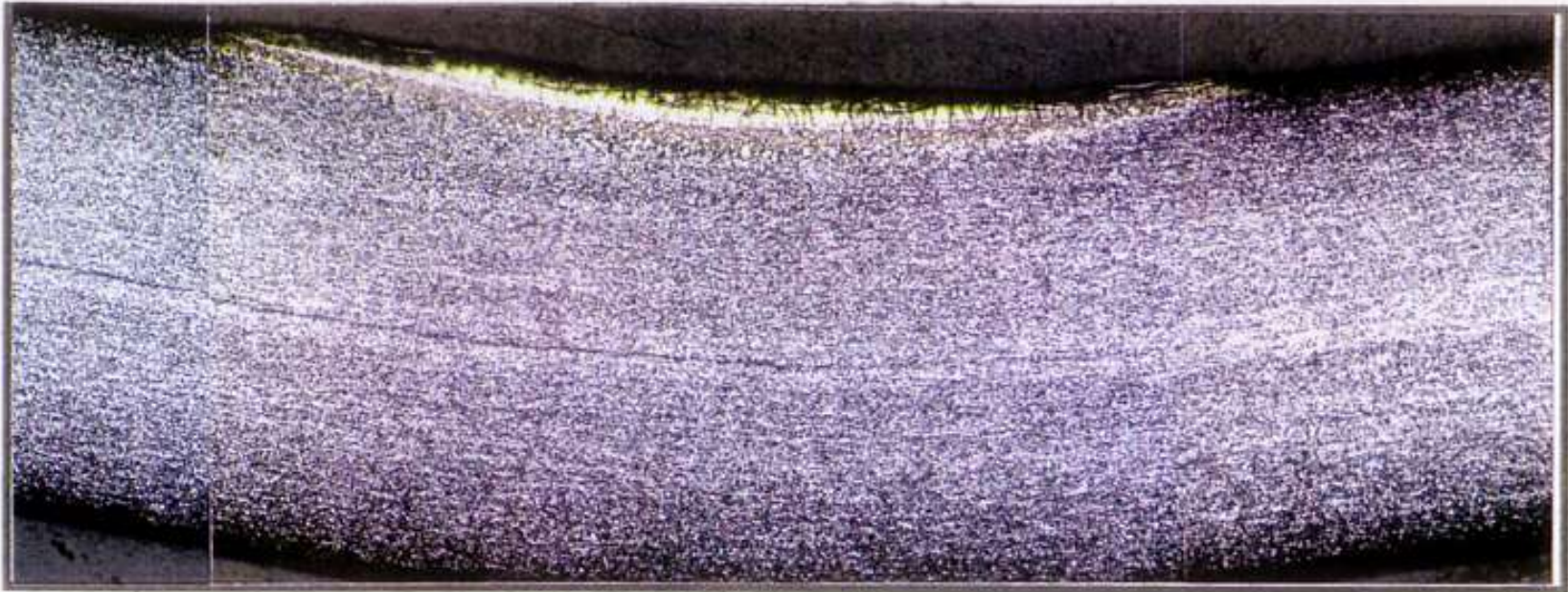


Fig.3-2 Relationship between number of laser scan and bending angle (1.0mm thickness)

Lateral expansion of bended plate

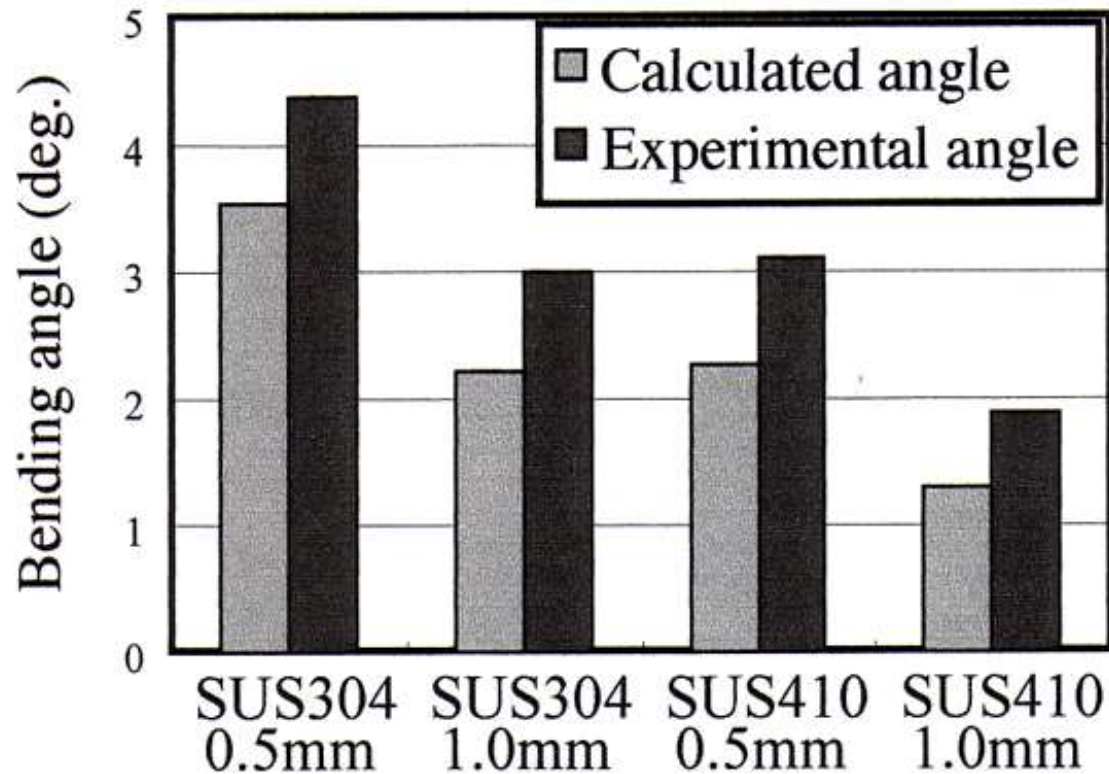


Laser power 310W
Spot diameter 3.9mm
Table speed 30mm/s
10pass
Thickness 1.0mm

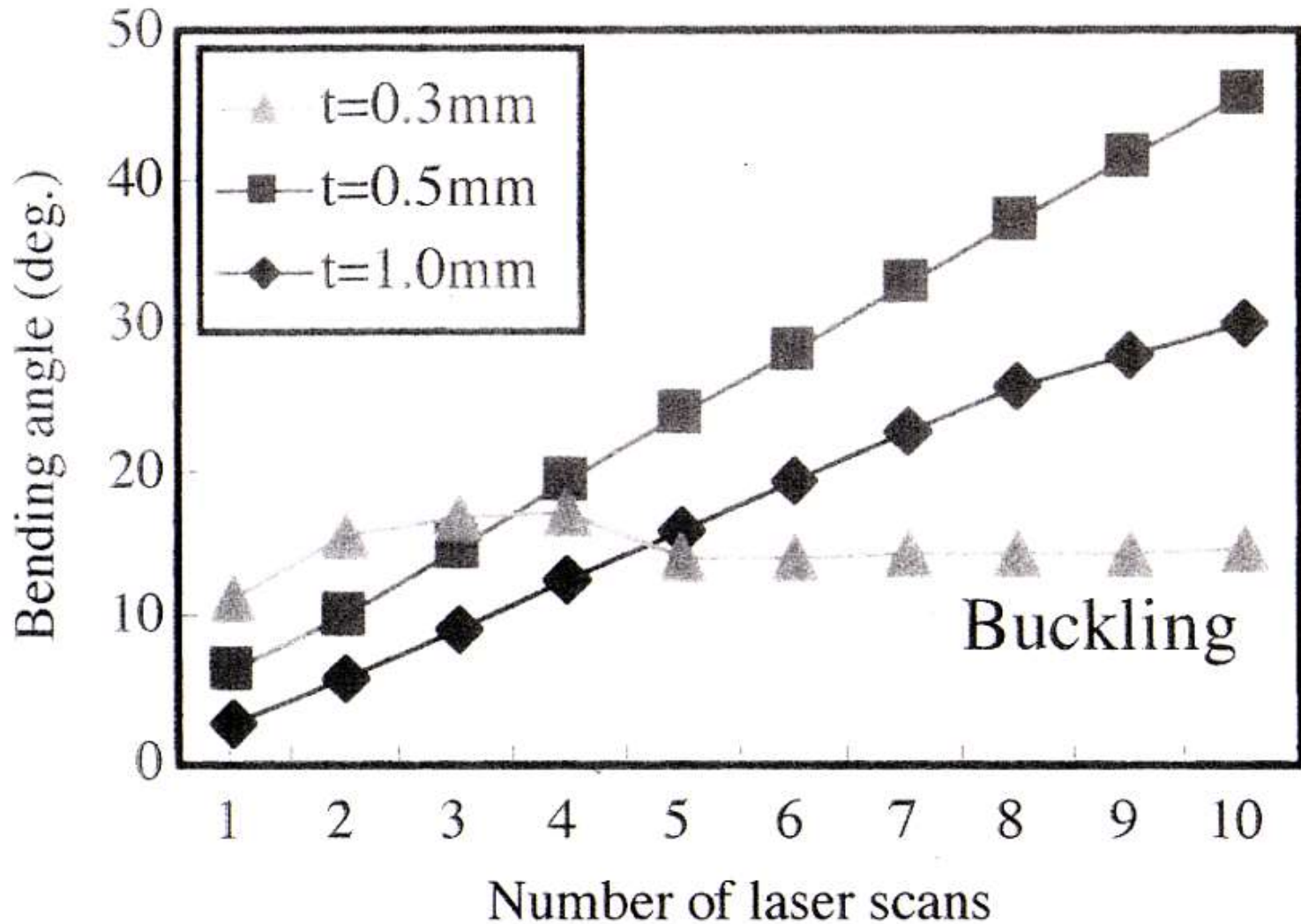
0.5mm

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 ϵ_A	1.46×10^{-2}	1.46×10^{-2}	9.36×10^{-3}	9.36×10^{-3}
Strain :bottom ϵ_B	4.15×10^{-3}	1.44×10^{-3}	1.27×10^{-3}	4.24×10^{-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

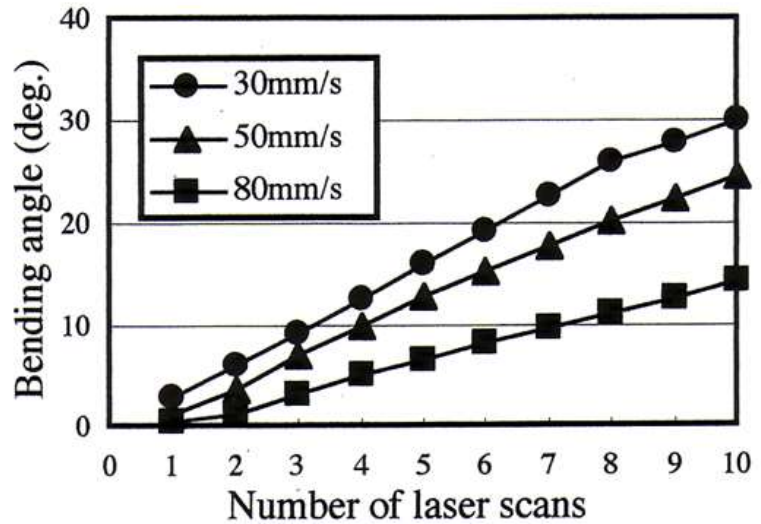


Fig. Relationship between number of laser scans and bending angle (SUS304 1.0mm thickness)

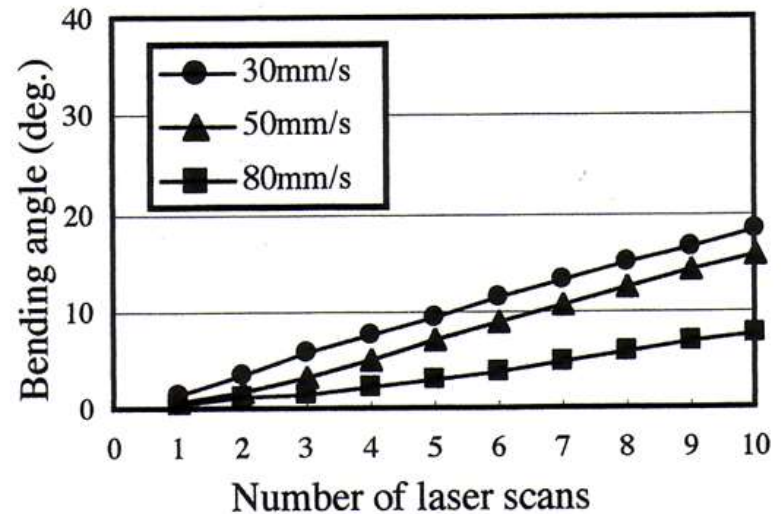


Fig. Relationship between number of laser scans and bending angle (SUS410 1.0mm thickness)

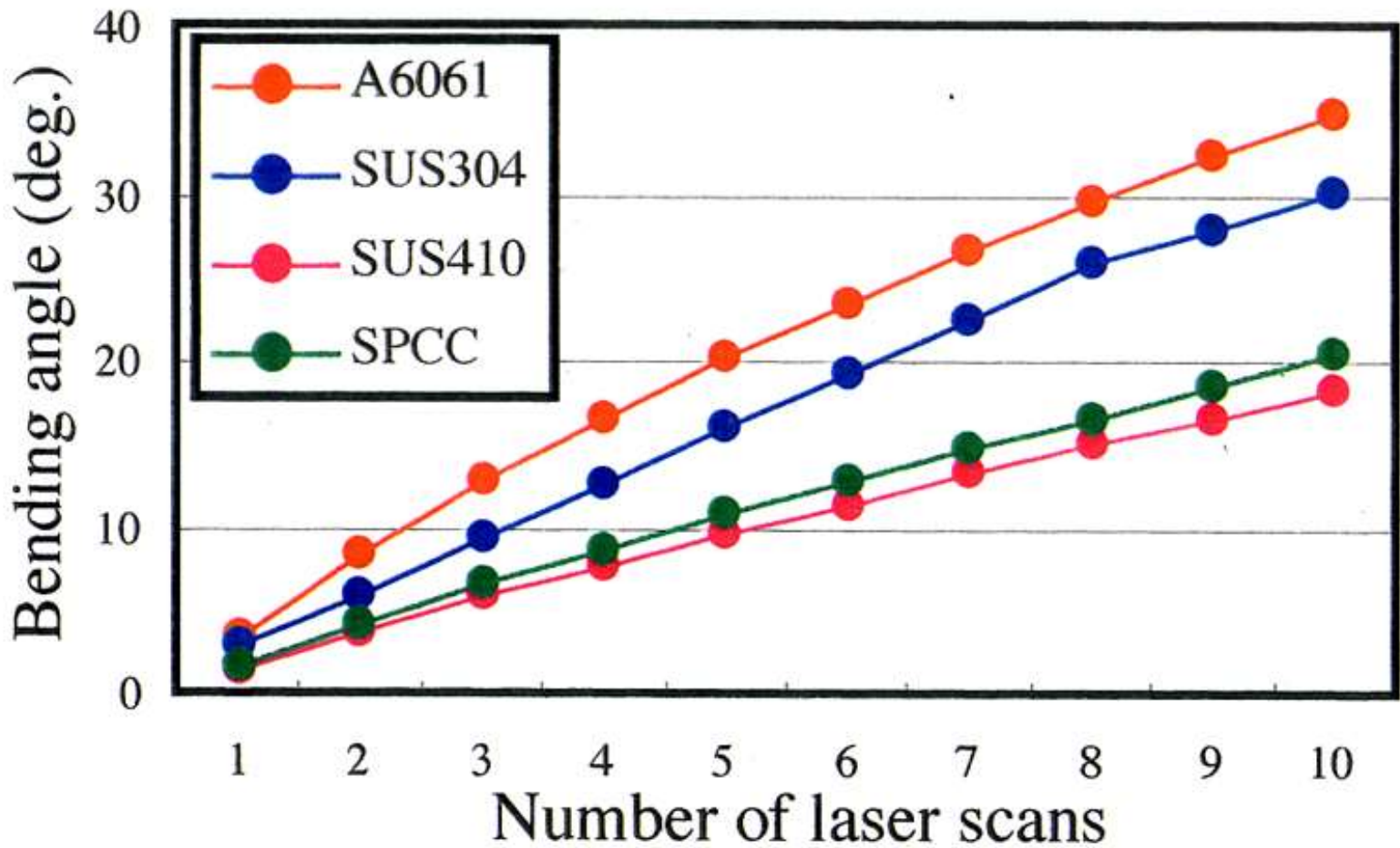
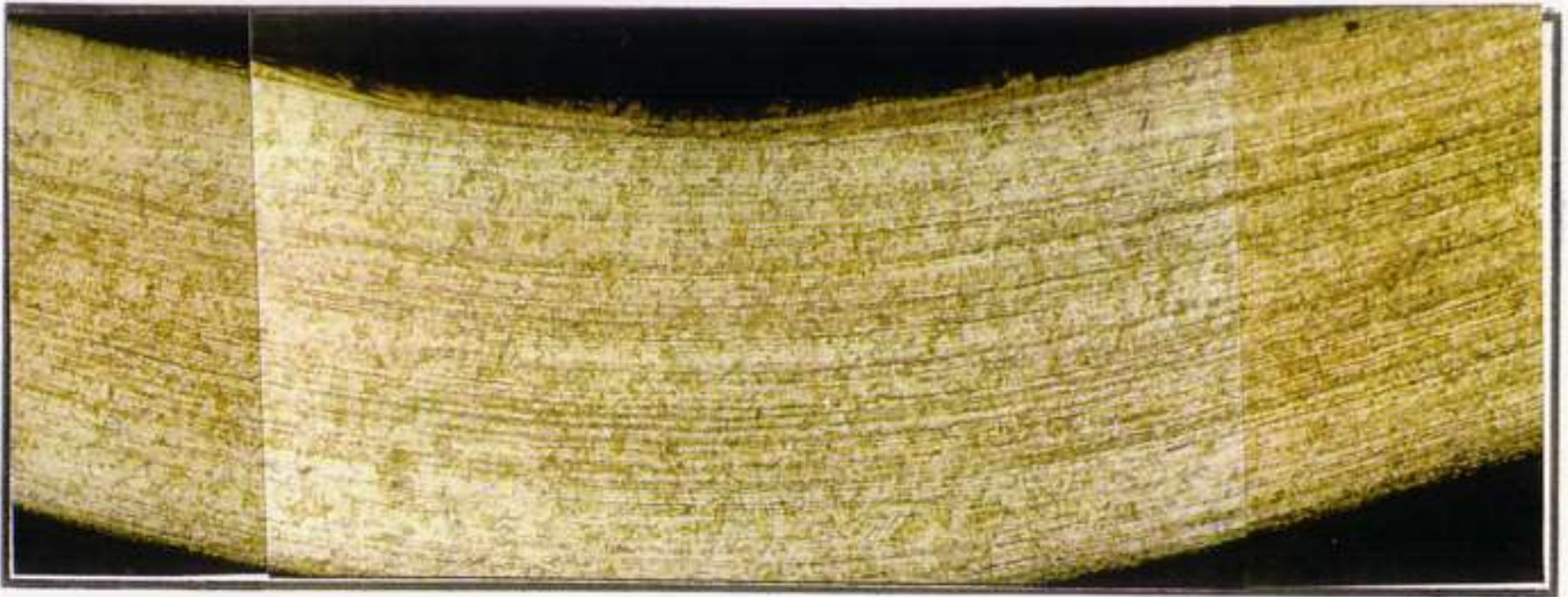


Fig. Bending angles of various materials with number of laser scans (1.0mm thickness)



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

0.5mm

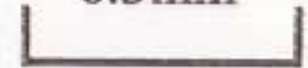


Fig.4-8(a) Cross section of SUS304 (1.0mm thickness)



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

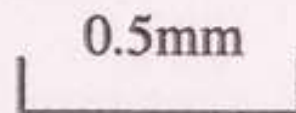


Fig.4-8(c) Cross section of SPCC (1.0mm thickness)

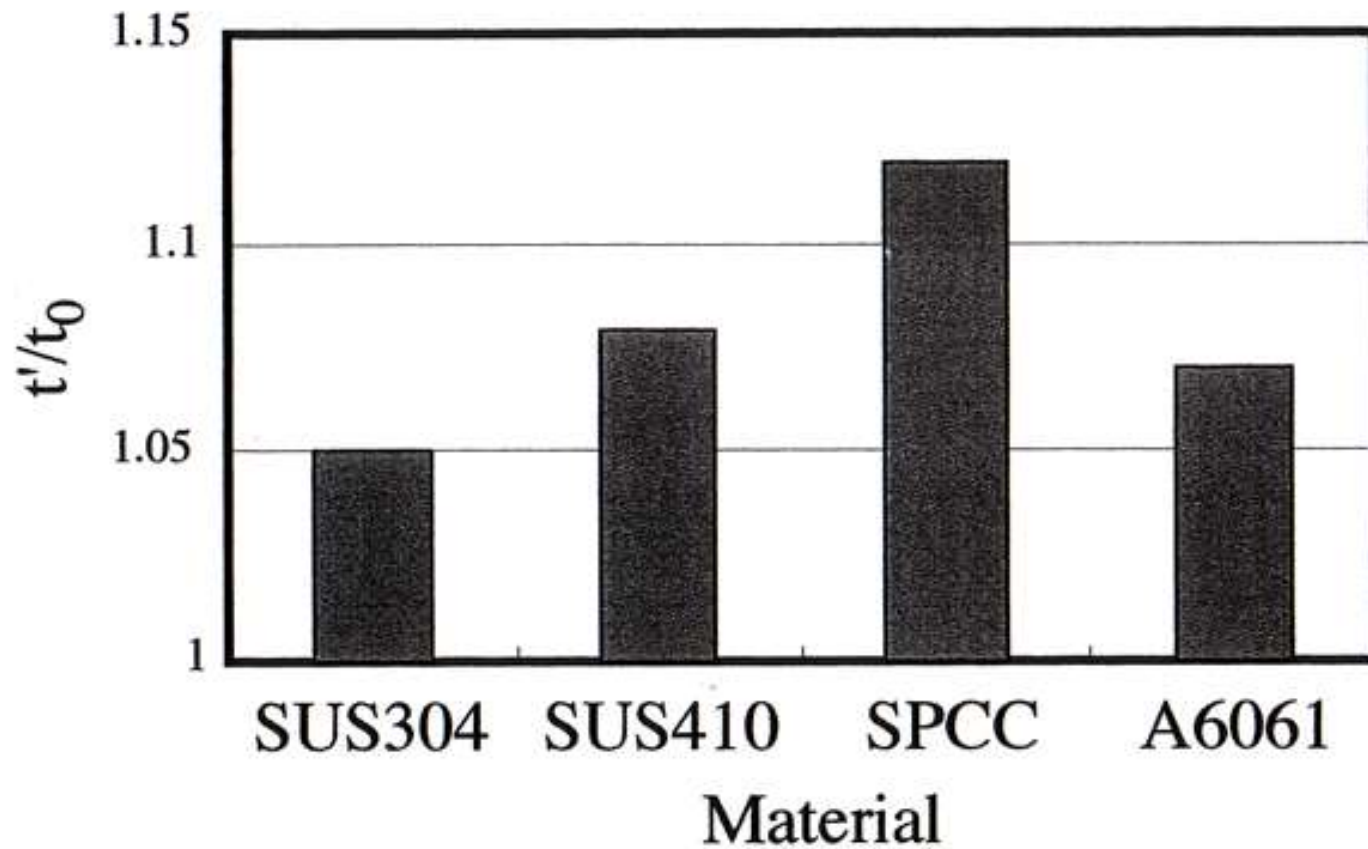


Fig. Surface expansion in each materials after 10 irradiations

Considering material properties

Table Physical properties of materials used

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

Calculation for thermal distribution of metal sheet

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

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

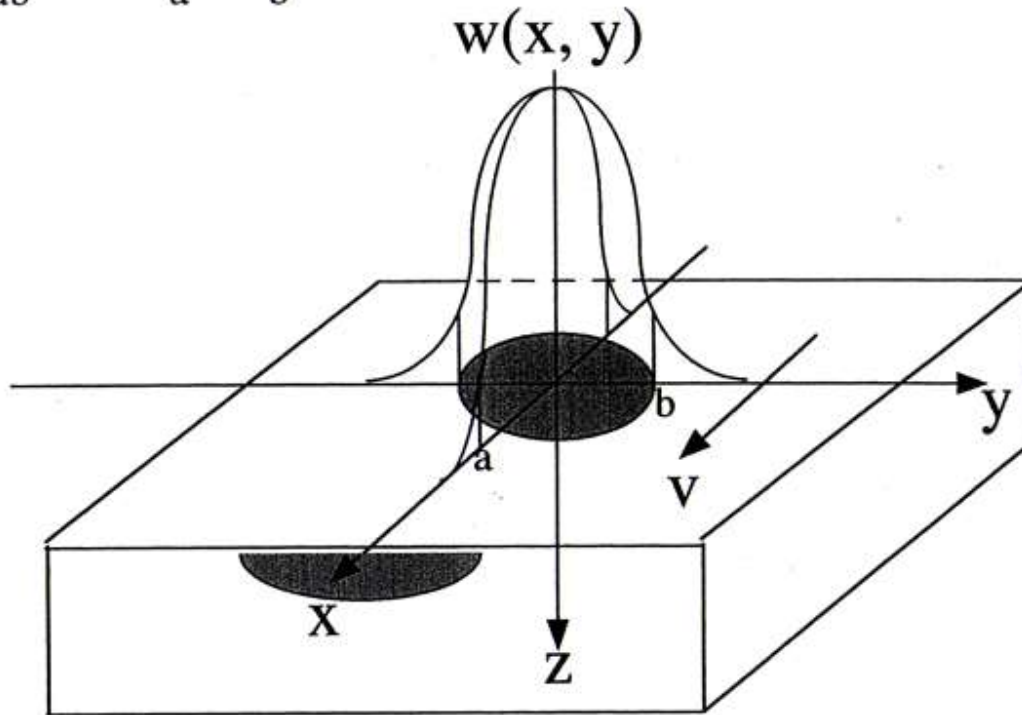


Fig. Gaussian heat source

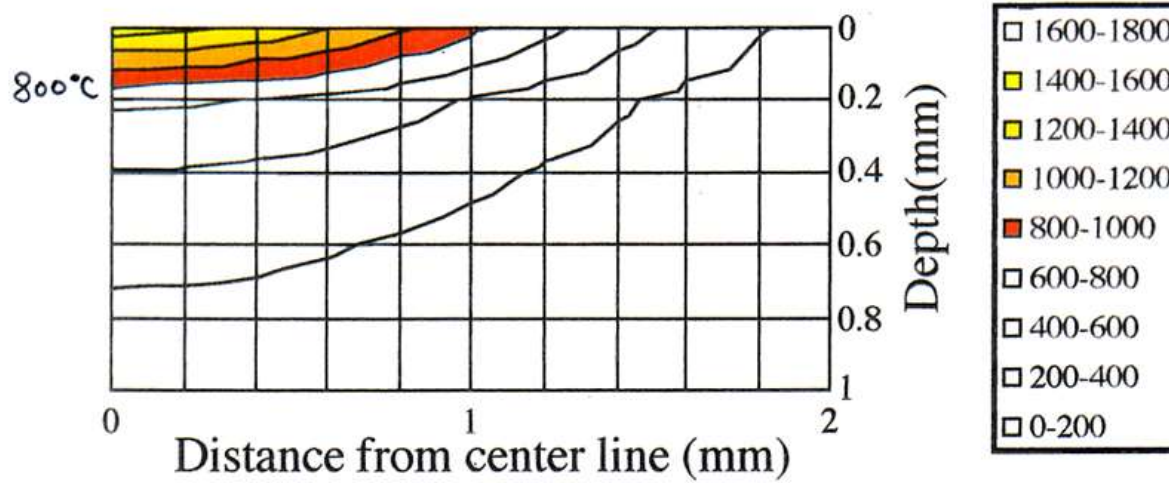


Fig. The isothermal lines of the peak temperature distribution (SPCC:thickness=1.0mm)

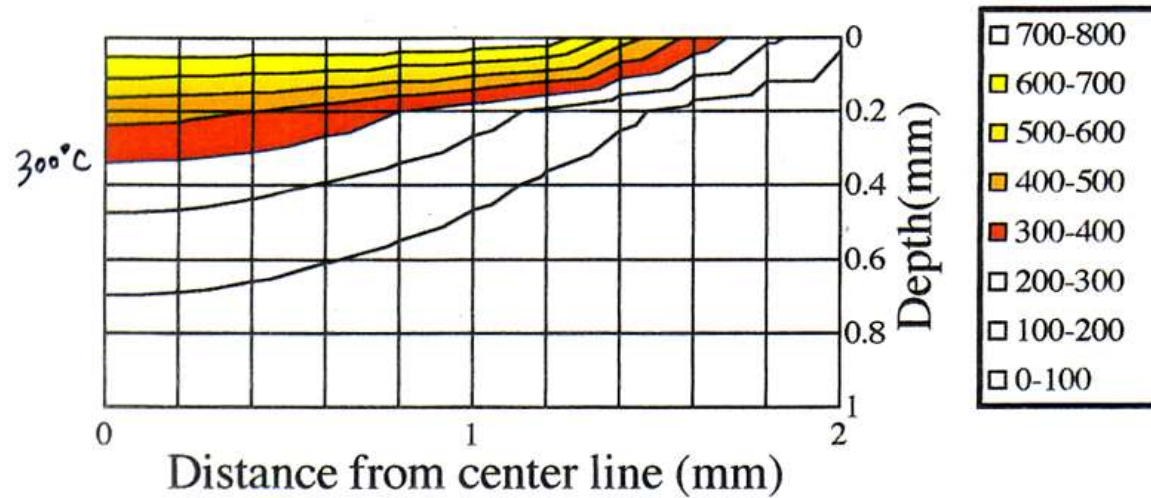


Fig. The isothermal lines of the peak temperature distribution (A6061:thickness=1.0mm)

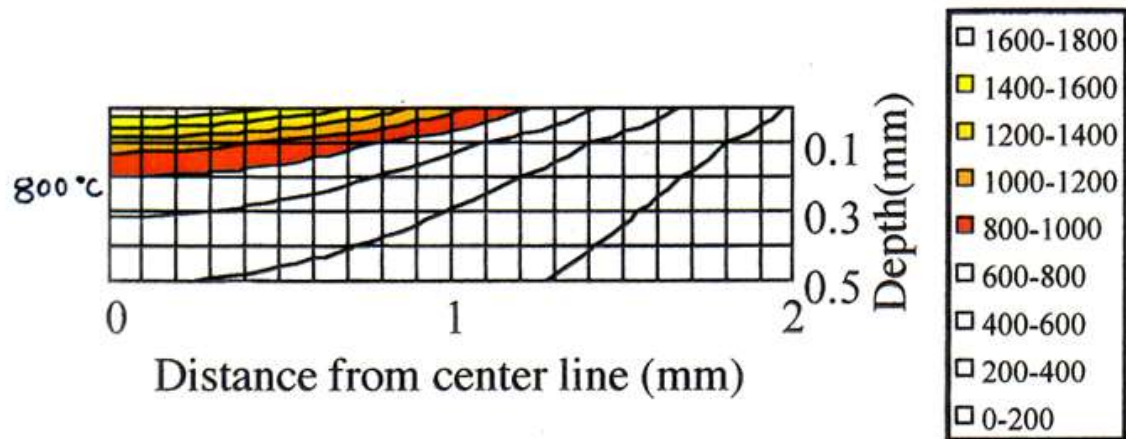


Fig. (a) The isothermal lines of the peak temperature distribution (SUS410 0.5mm thickness)

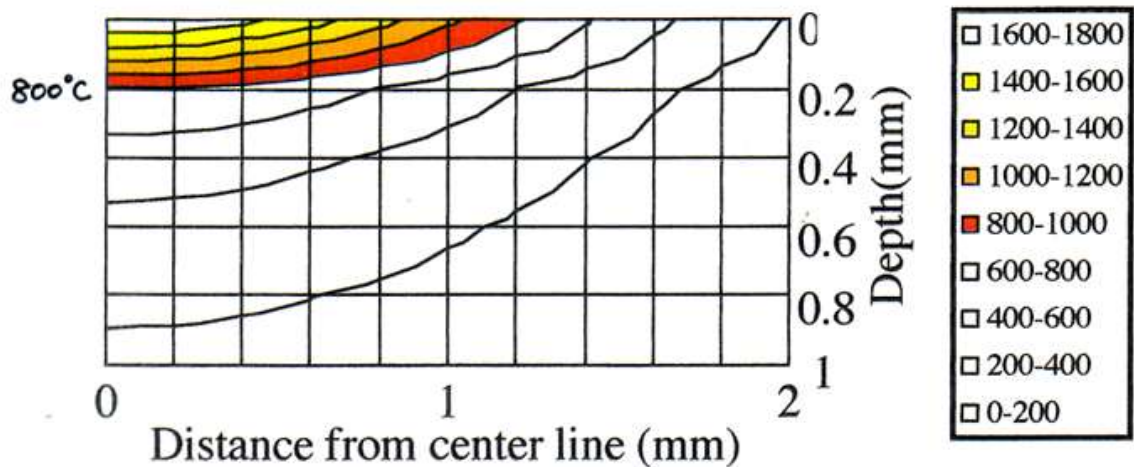
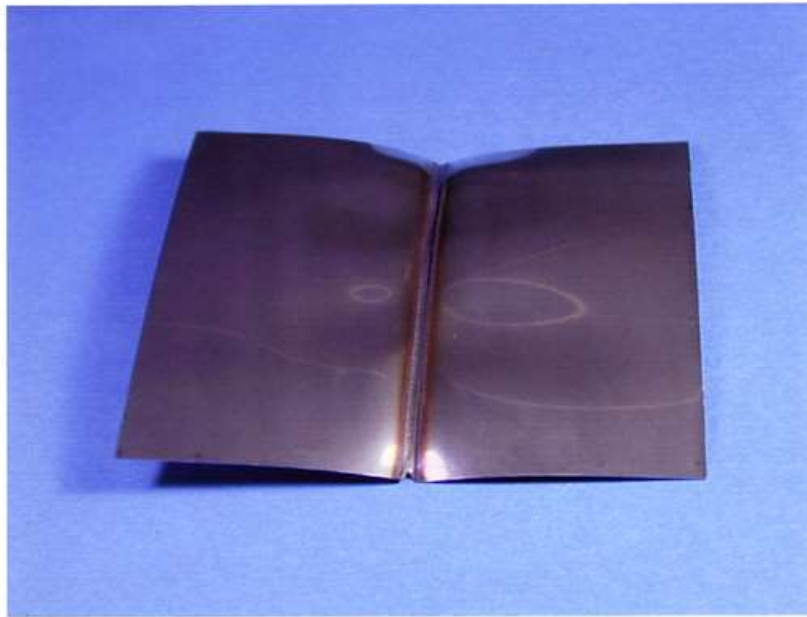
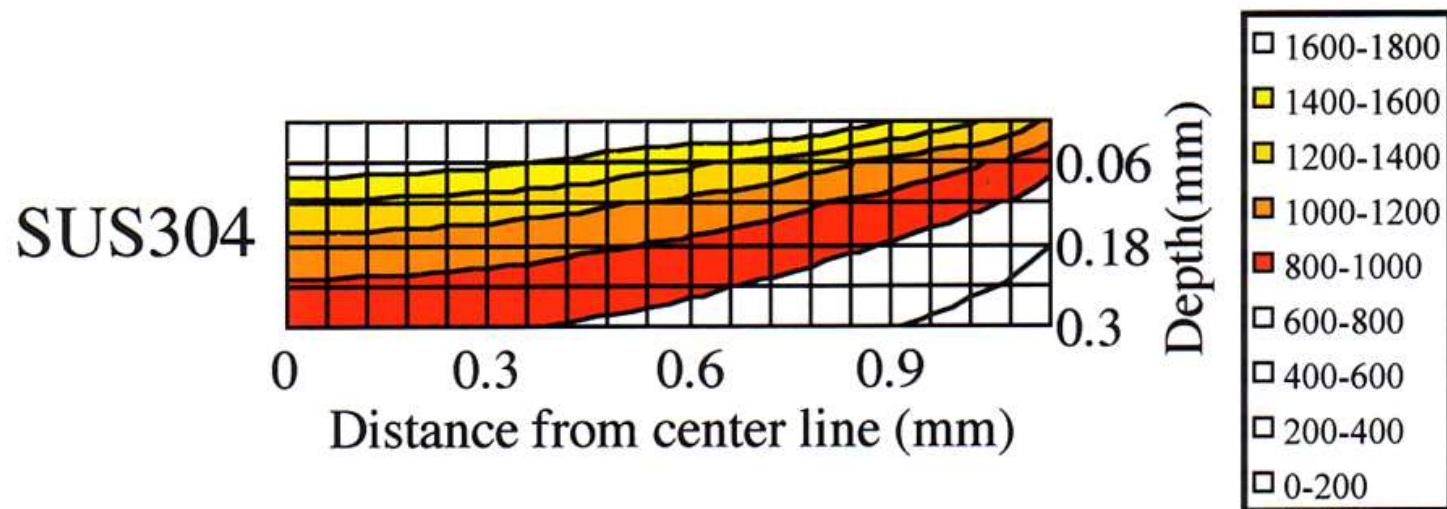


Fig. (b) The isothermal lines of the peak temperature distribution (SUS410 1.0mm thickness)

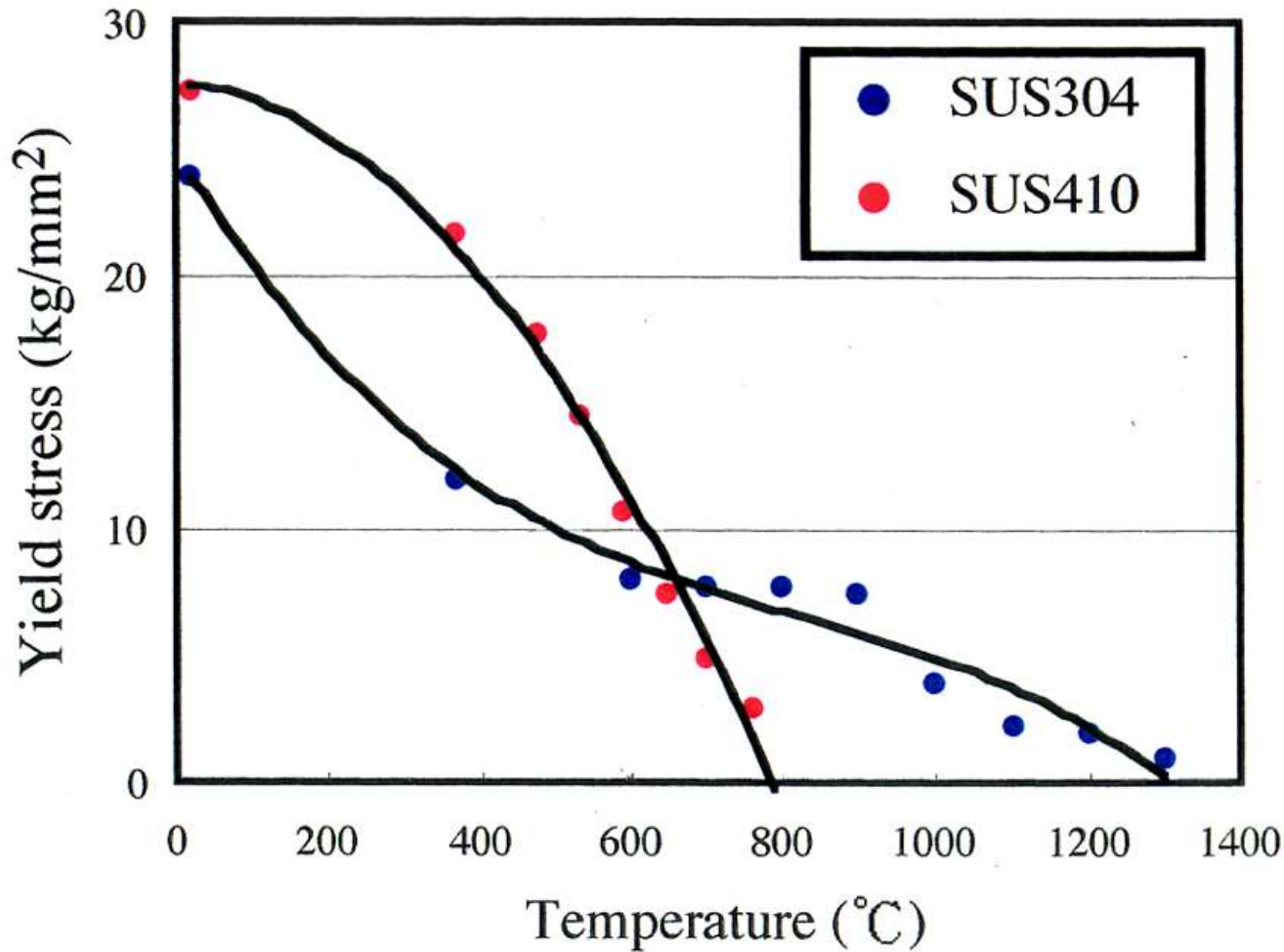


$t=0.3\text{mm}$

Fig. Appearance of deformed SUS304 plate(10pass)



Temperature dependence of yield stress



Relationship between yield stress and temperature in stainless steels

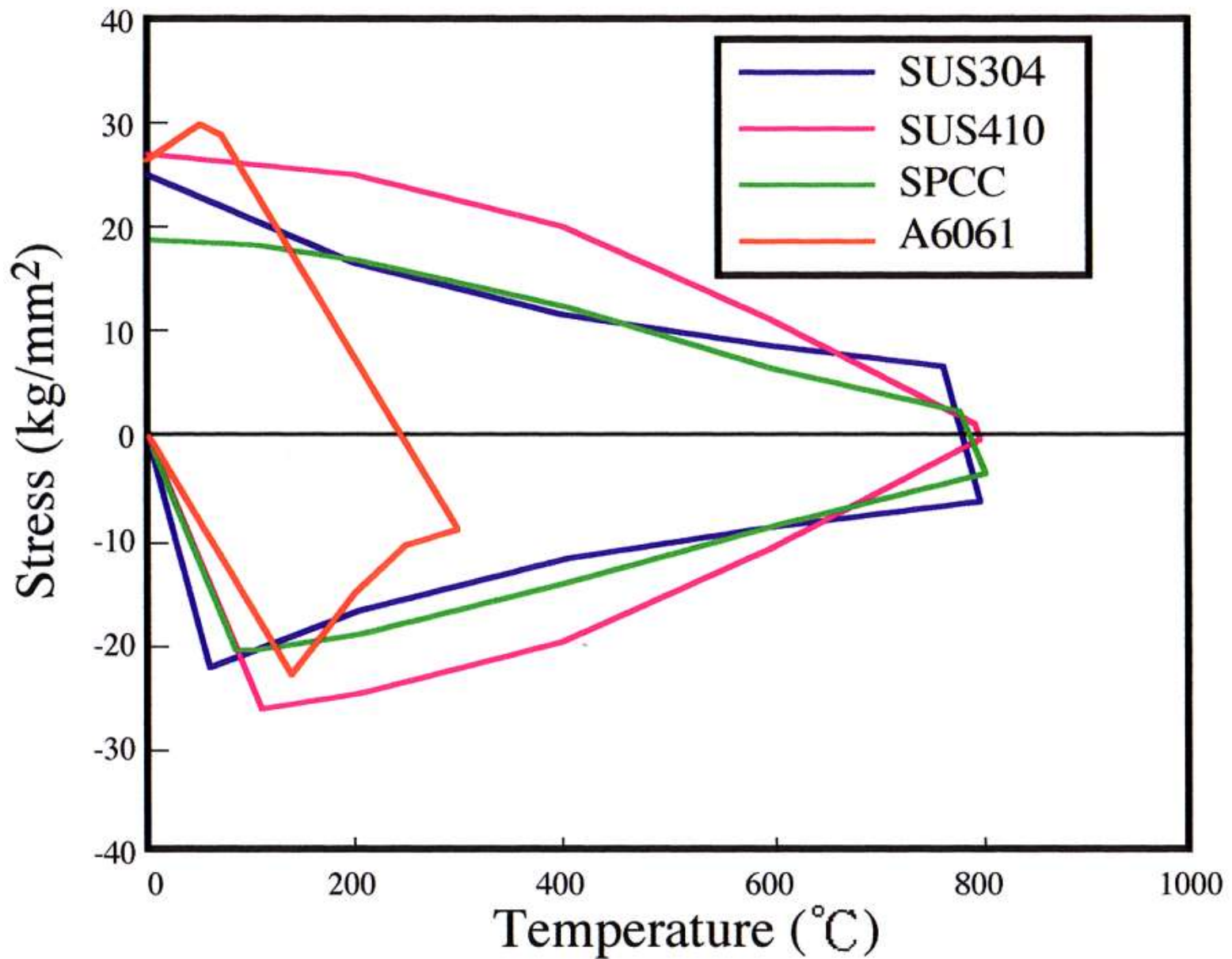


Fig. Thermal stress developed in stainless steel during single thermal cycle

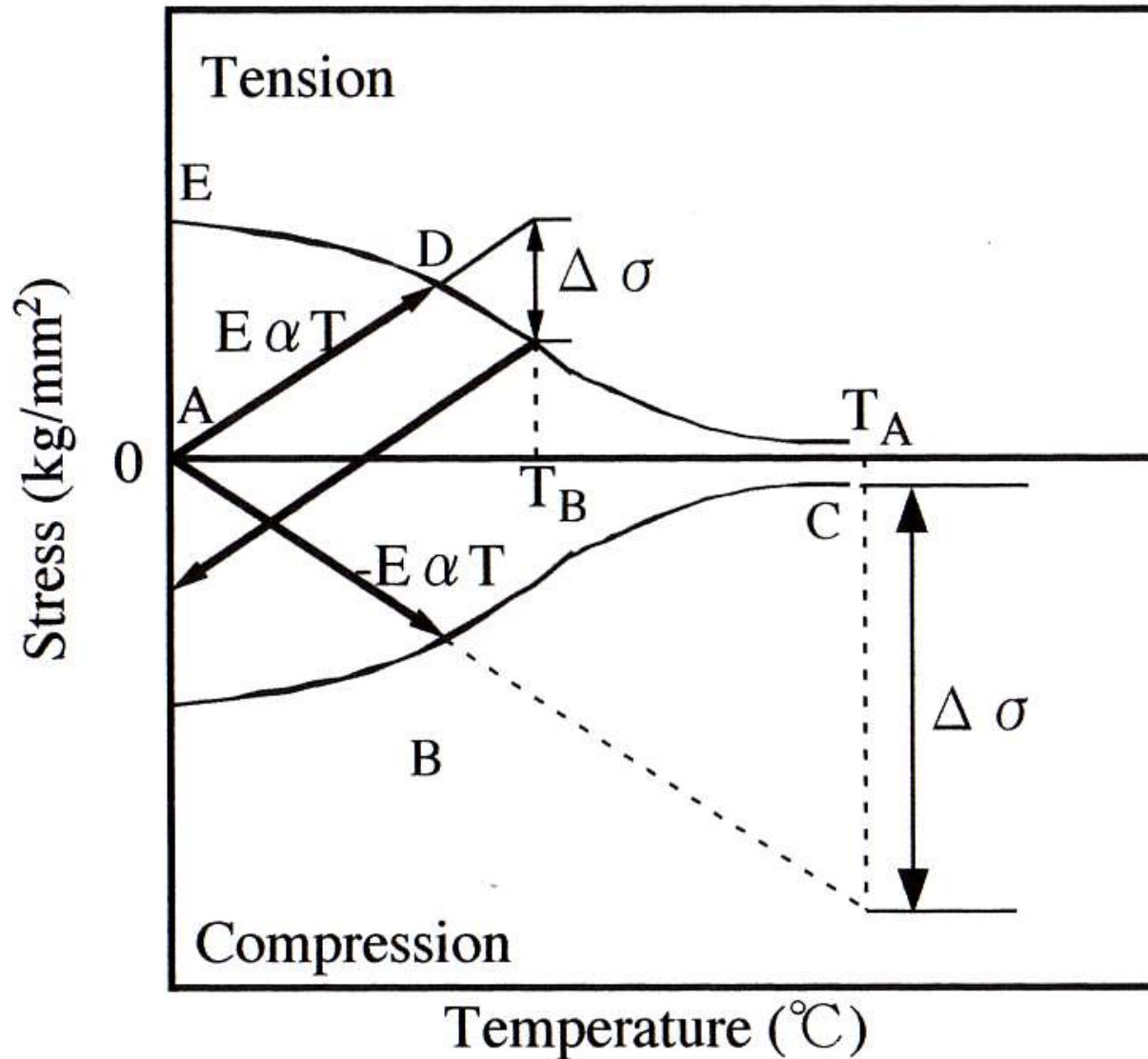
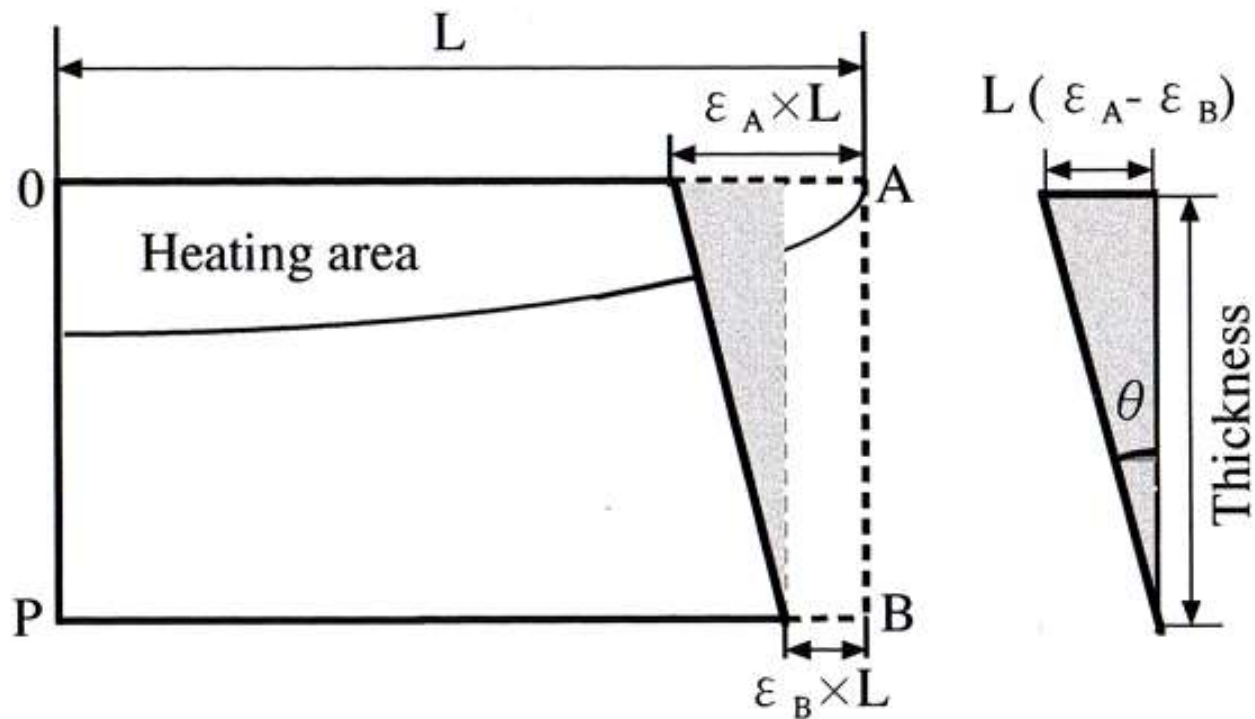
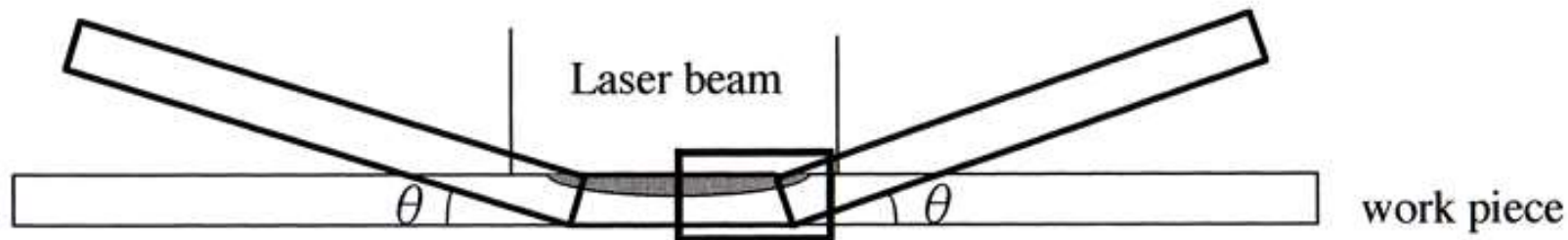


Fig. (a) The typical thermal stress during single thermal cycle

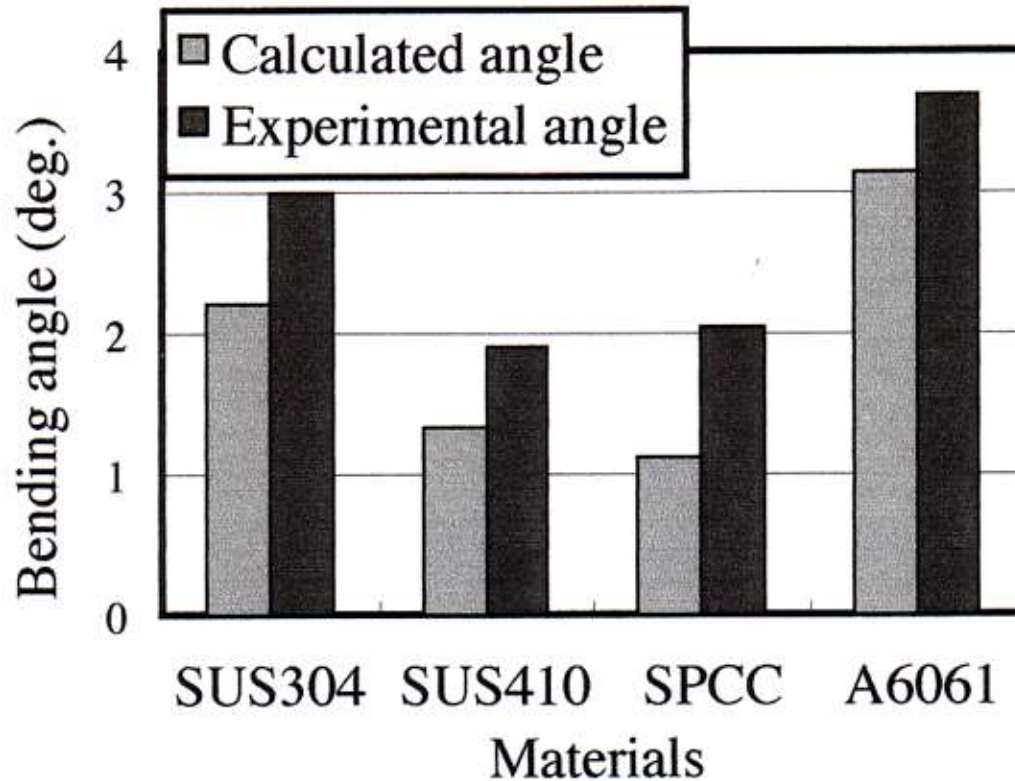


$$\text{Bending angle} = 2 \tan^{-1} \left(\frac{L(\epsilon_A - \epsilon_B)}{\text{Thickness}} \right)$$

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 ε_A	1.46×10^{-2}	9.36×10^{-3}	9.16×10^{-3}	5.7×10^{-3}
Strain :bottom ε_B	1.44×10^{-3}	2.11×10^{-4}	2.21×10^{-3}	1.71×10^{-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**

