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"Fast Reactor Thermal Transients"
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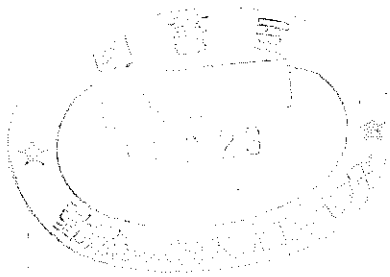
A Parametric Study on the Thermal Stresses of Straight Pipes under the Typical FBR Thermal Transient Conditions



T. KANO Power Reactor and Nuclear Fuel Development Corporation Tokyo, JAPAN

J. ASAKURA Century Research Center, Tokyo, JAPAN

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1. INTRODUCTION

The purpose of this study is to have a some basic data on the transient thermal stress characteristics of a straight pipe in which the flowing sosium temperature may vary fast under the various FBR transient operational conditions. The parametric survey is done on the following main parameters shown below;

Wall Thickness

Material (SUS304, $2\frac{1}{4}$Cr-1Mo)

Wall Thickness/Inner Radius

Sodium Temperature Changing Rate (°C/sec)

Total Sodium Temperature Change (°C)

Sodium Temperature Changing Pattern

Temperature Dependant Material Properties or not

2. BASIC DESCRIPTIONS OF THE CALCULATION

Used Program:	ANSYS
Element:	STIF35 (Linear Temperature Element--Axisymmetric)
	STIF 2 (Constant Strain Element--Axisymmetric)
Geometry:	Axisymmetric pipe model as shown in Fig.1.
Material:	SUS304 or 2-1/4Cr-1Mo. Temperature dependant material properties given in the SAN781-1 "Design Guide for LMFBR Sodium Piping" are used except the case No.59 to 64. Heat transfer coefficients are calculated using the Seban-Simazaki's Equation shown in the above reference.
Load condition:	Typical sodium temperature condition is shown in Fig.2.
Boundary condition:	as shown in TABLE 1 and TABLE 2.

3. RESULTS

The calculated Results are summarized in Table 3 and the effect of the various main parameters are shown in Fig.4~11.

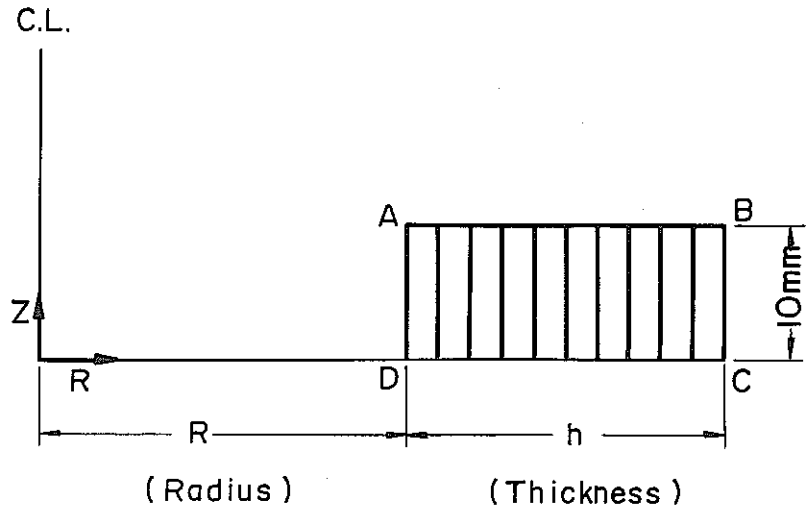


Fig. 1 Axisymmetric pipe model

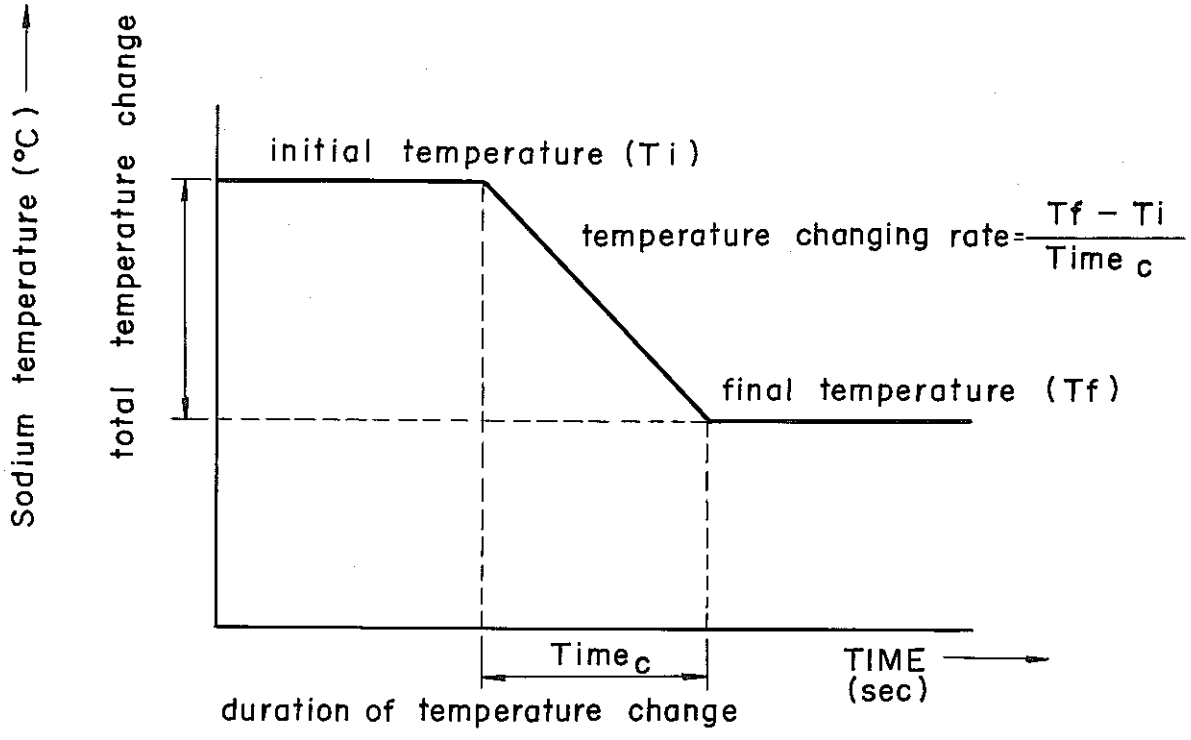


Fig. 2 Sodium temperature condition

TABLE 1 THERMAL BOUNDARY CONDITION

boundary	condition
$\overline{AD}$ (in Fig. 1)	convection surface (Sodium flowing)
$\overline{ABC}$ (in Fig. 1)	insulated

TABLE 2 KINEMATIC BOUNDARY CONDITION

boundary	condition
$\overline{CD}$ (in Fig. 1)	Z-direction displacements fixed
$\overline{AB}$ (in Fig. 1)	Z-direction displacements coupled

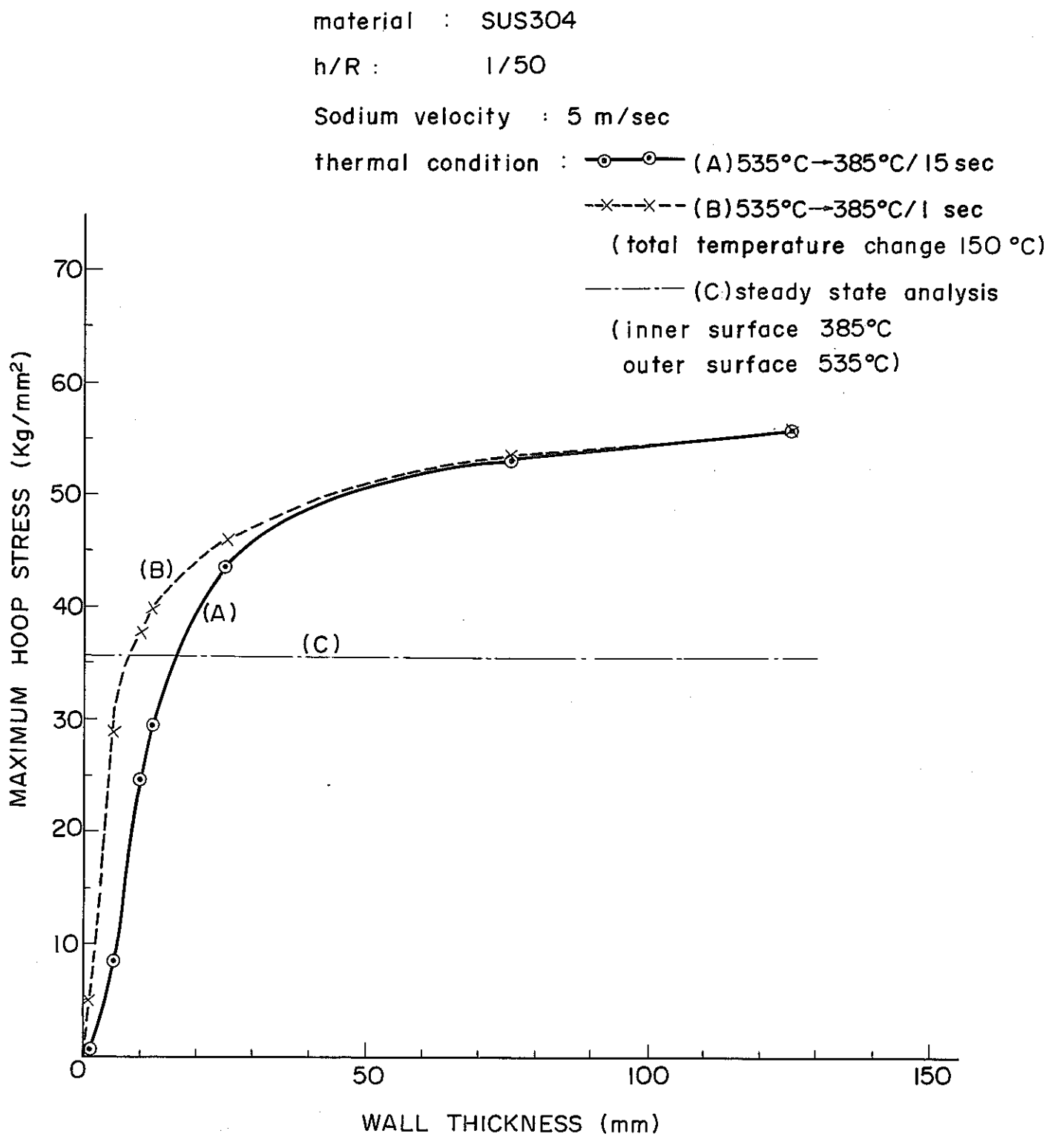


Fig. 4 MAXIMUM HOOP STRESS AND WALL THICKNESS

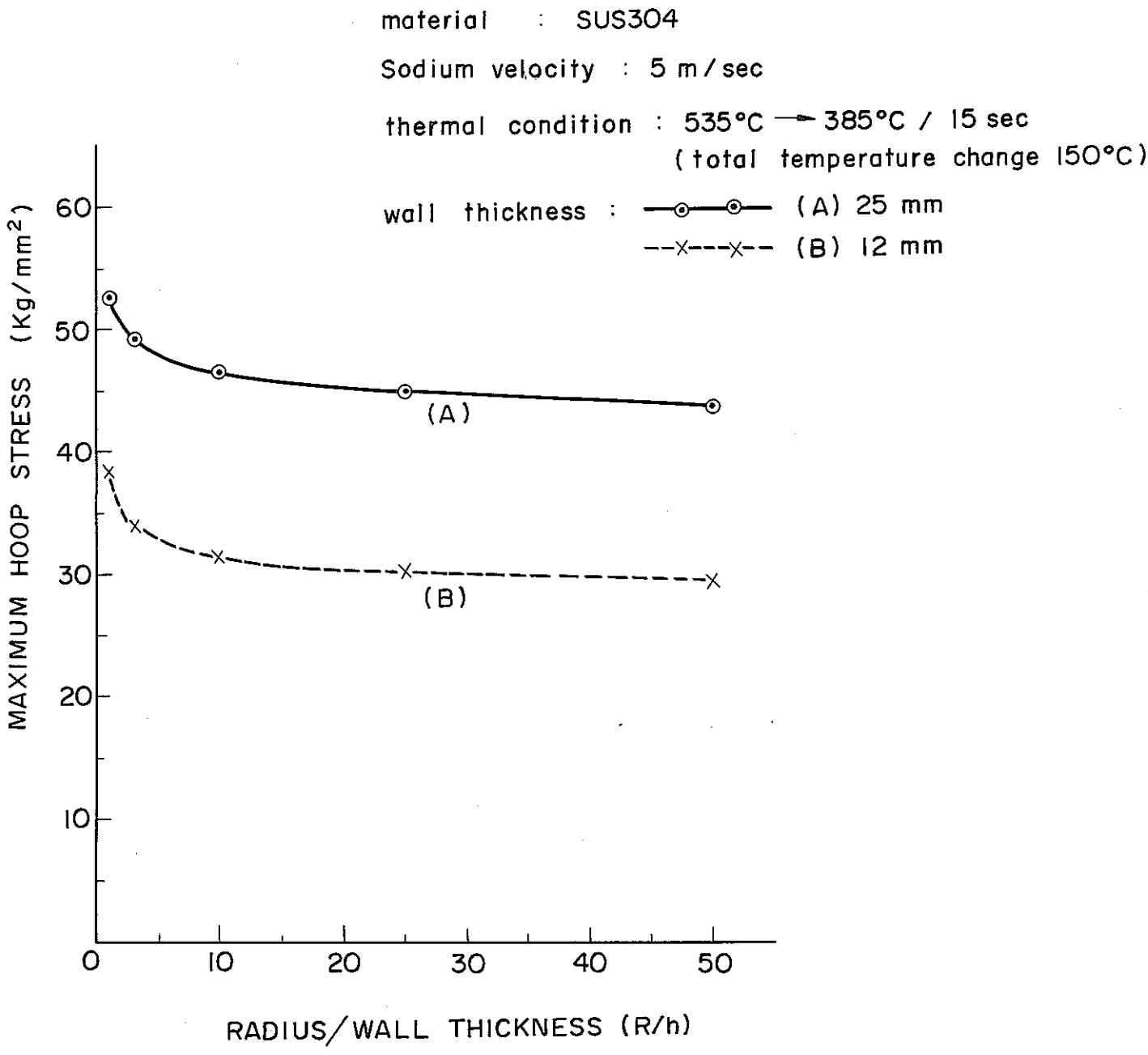


Fig. 5 RADIUS / WALL THICKNESS (R/h) AND MAXIMUM HOOP STRESS

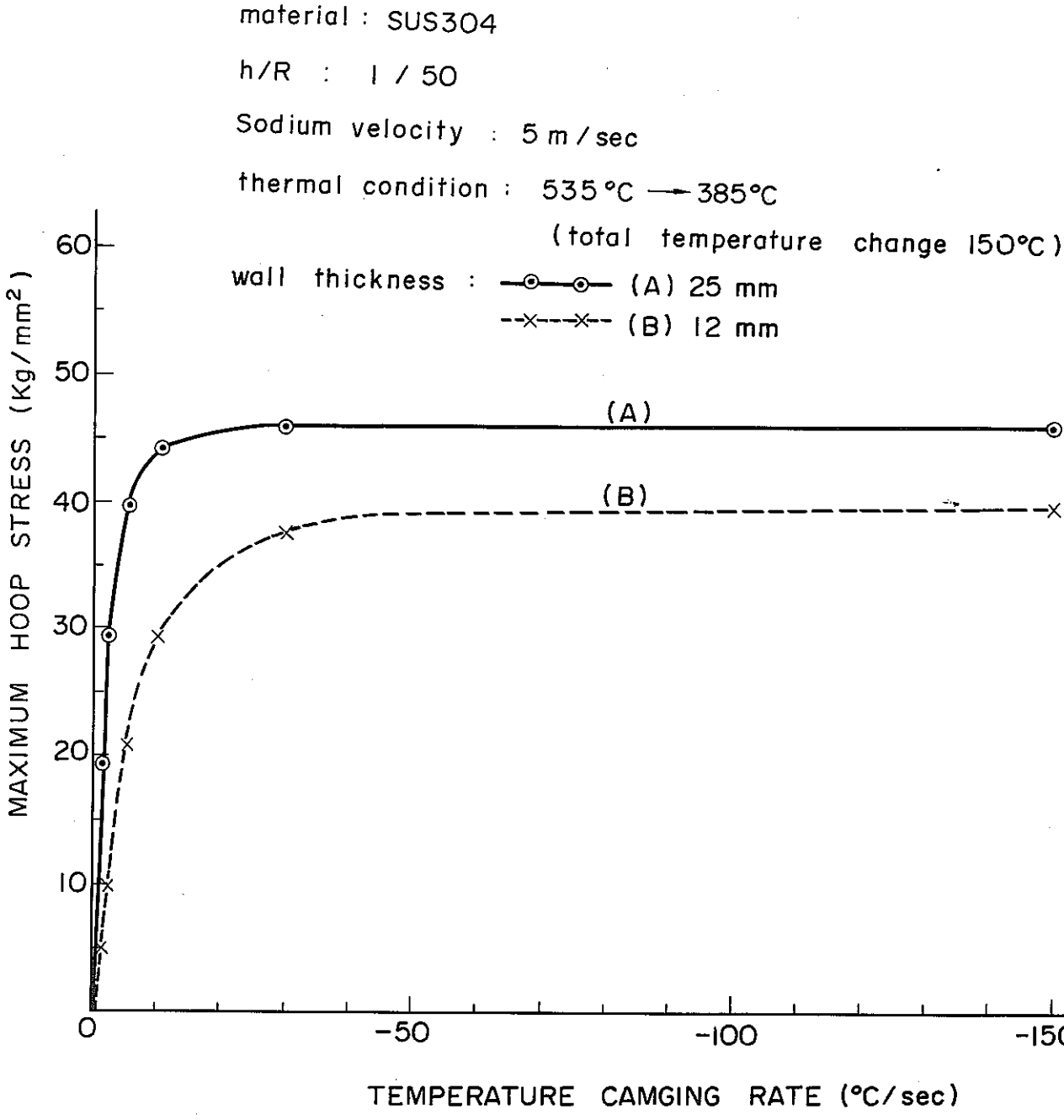


Fig. 6 MAXIMUM HOOP STRESS AND TEMPERATURE CHANGING RATE

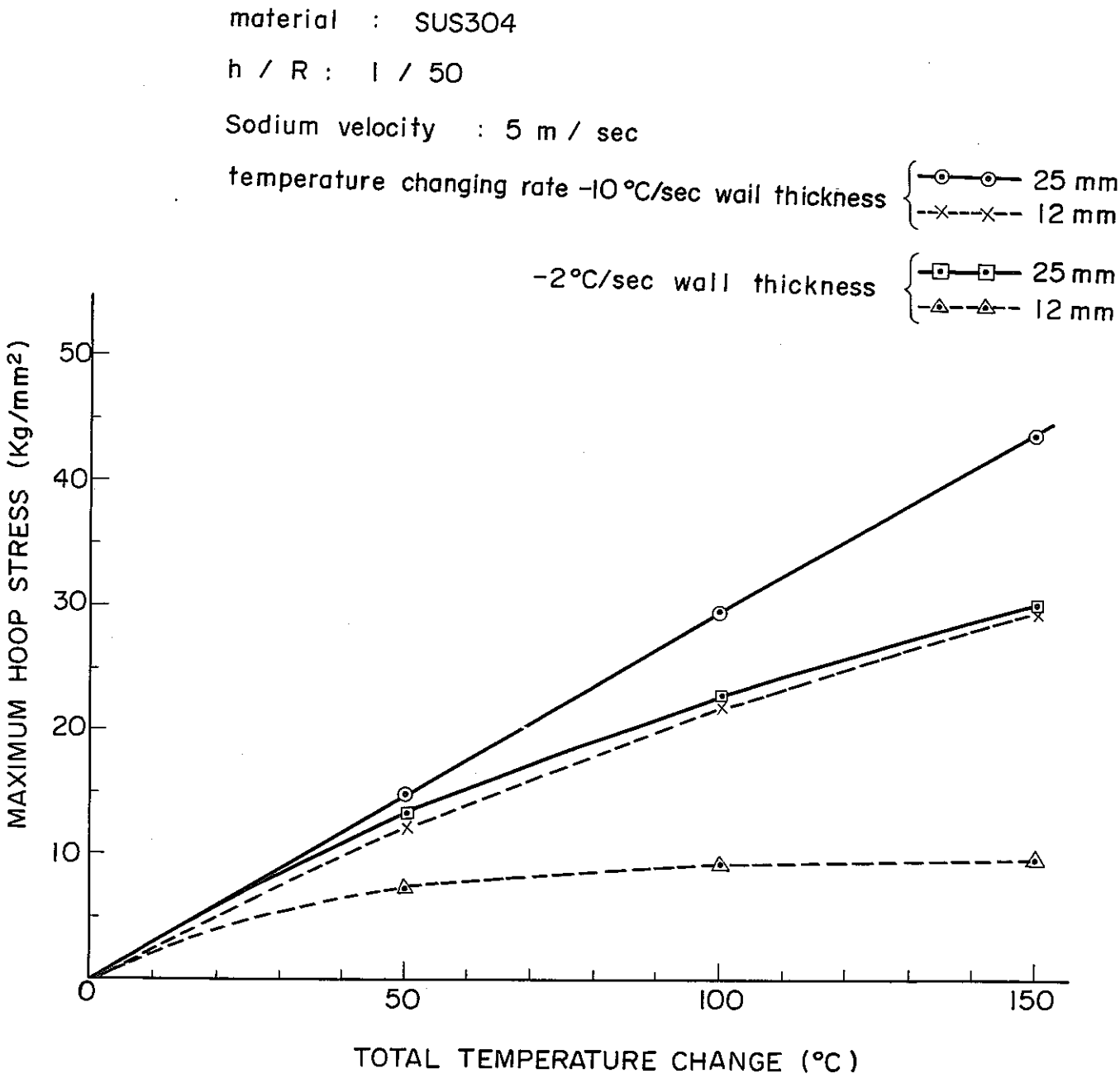


Fig. 7 MAXIMUM HOOP STRESS AND TOTAL TEMPERATURE CHANGE

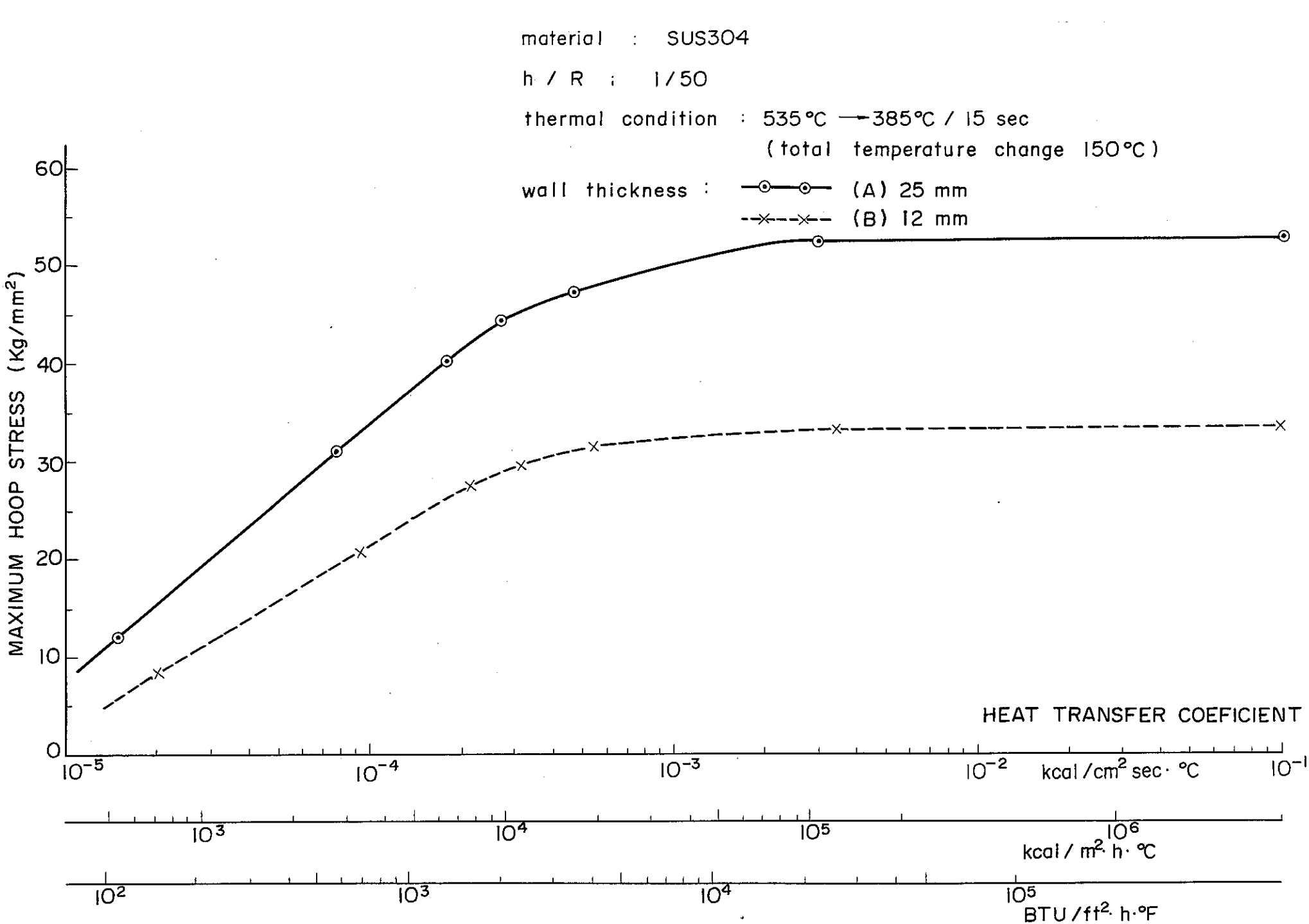


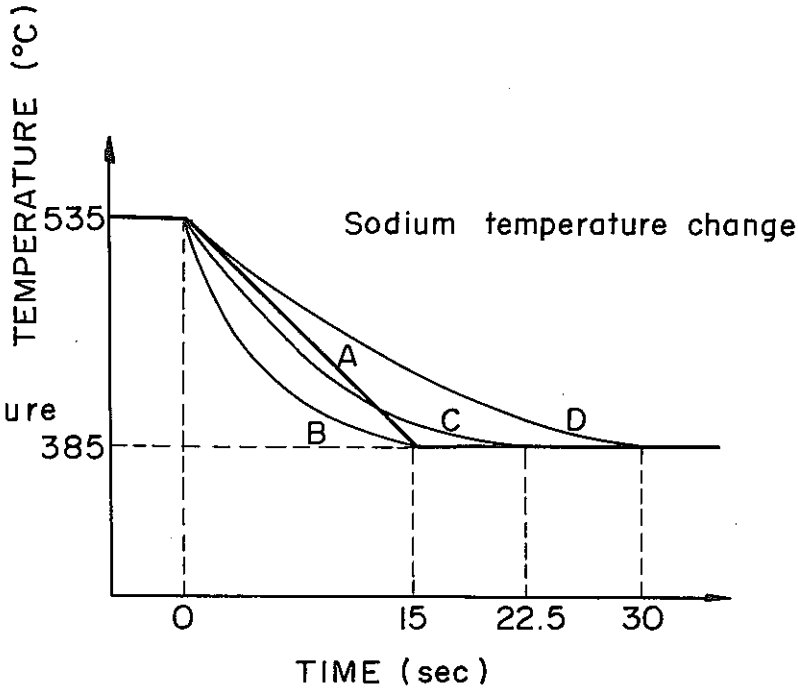
Fig. 8 MAXIMUM HOOP STRESS AND HEAT TRANSEER COEFFICIENT

material : SUS304

h / R : 1/50

wall thickness : 25 mm

thermal condition : 535 °C → 385 °C
(total temperature change 150°C)



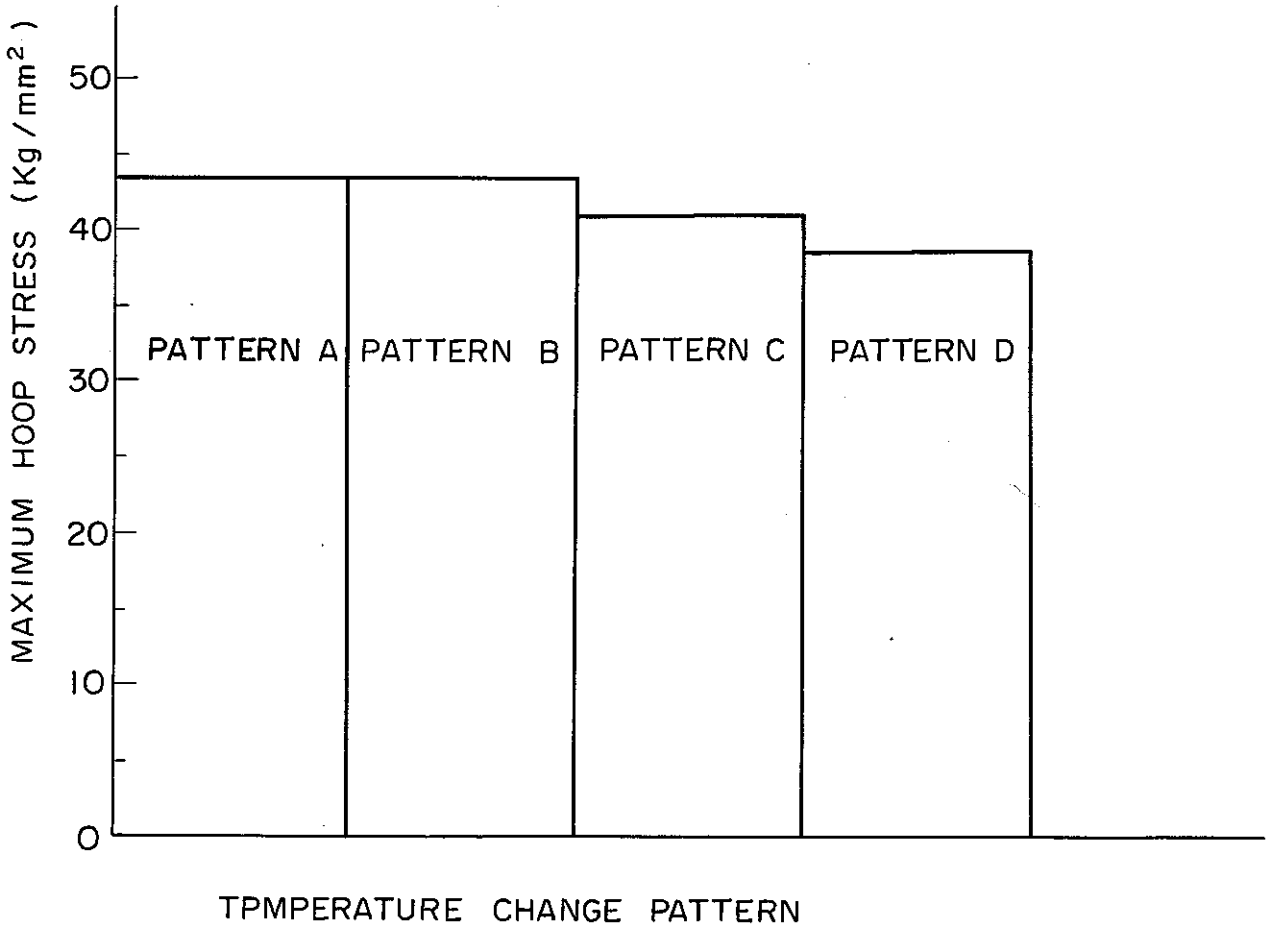


Fig. 9 MAXIMUM HOOP STRESS AND TEMPERATURE CHANGING PATTERN

materinal : A — SUS304
B — $2\frac{1}{4}$Cr-1Mo
C — $2\frac{1}{4}$Cr-1Mo

h / R : 1/50

Sodium velocity : 5 m /sec

thermal condition :

535°C → 385°C / 15 sec (total temperature change 150°C)
: material property { ⊙ function of temperature
△ fixed value (535 °C)
⊡ fixed value (385 °C)

485°C → 385°C / 20 sec (total temperature change 100°C)
: material property { × function of temperature

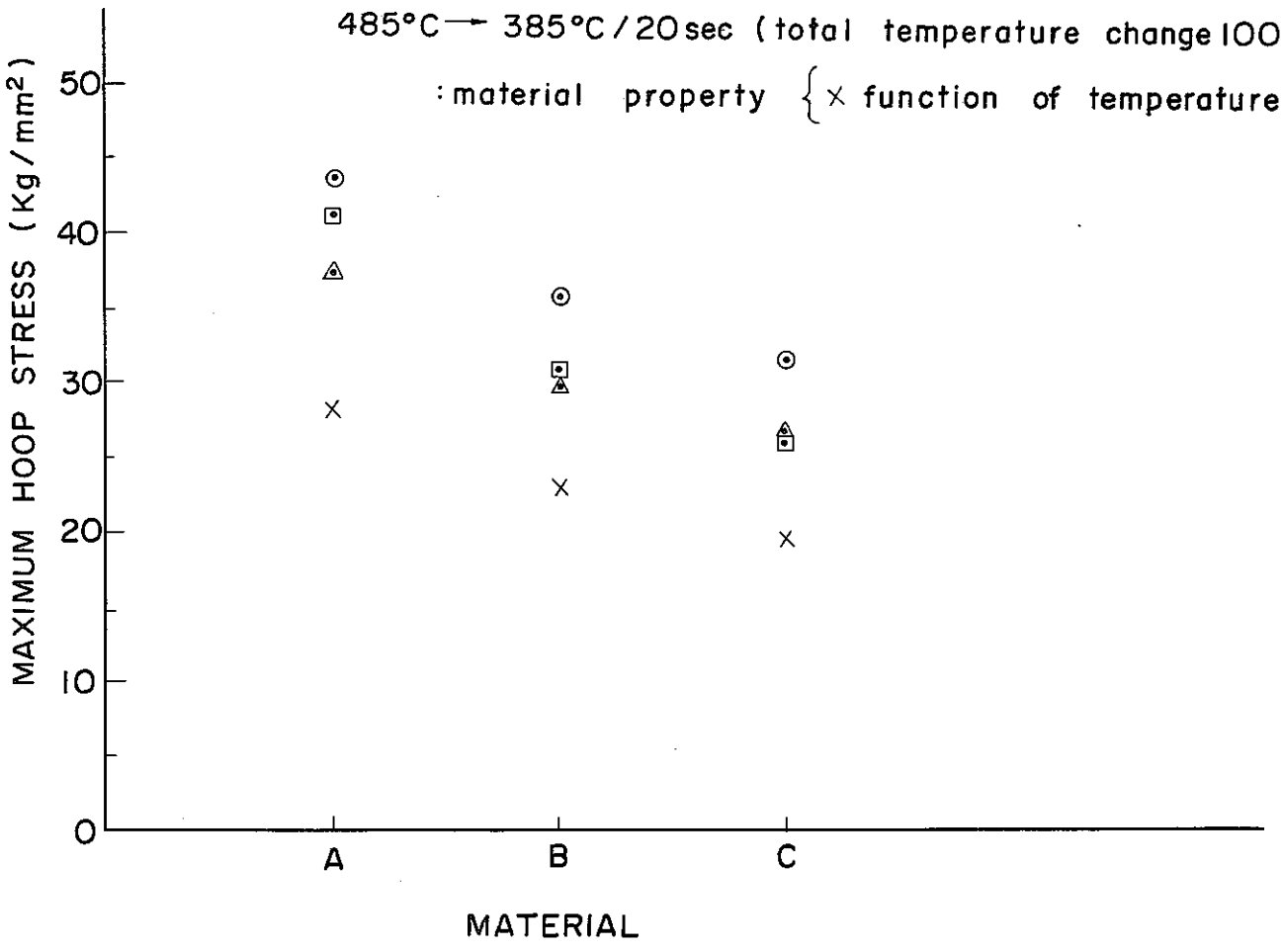


Fig. 10 MAXIMUM HOOP STRESS AND MATERIAL

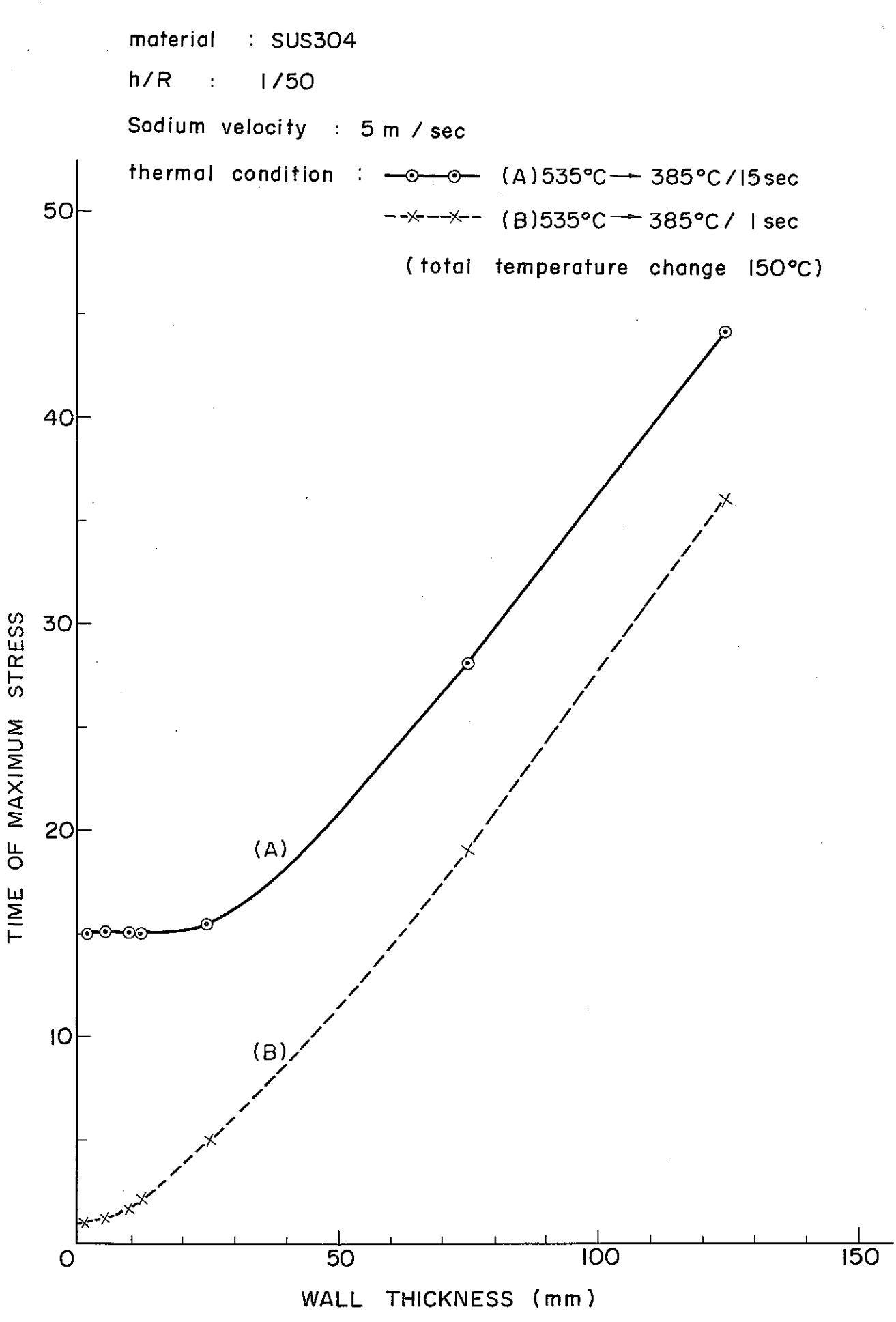


Fig.11 TIME OCCURING MAXIMUM STRESS AND WALL THICKNESS

TABLE 3-1 PARAMETRIC STUDIES FOR THERMAL TRANSIENT STRESSES OF STRAIGHT PIPES

Problem NO.	Parameter	Material	Thickness (h) mm	Radius (inner) (R) mm	$\frac{h}{R}$	Inner Fluid	Fluid Velocity m/sec	Outside Thermal Condition	Initial Temperature Ti °C	Final Temperature Tf °C	Total Temperature Change °C	Duration of Trangsient Temperature Time sec	Temperature Changing Rate °C/sec	Pattern of Temperature Change	Heat Transfer coefficient Kcal/cm^2·sec·°C x 10^{-4}	Maximum Hoop Stress kg/mm^2	Time of Maximum Stress sec
1	Wall Thickness	SUS304	1	50	1/50	Na	5	Insulated	535	385	150	15	-10	Linear	5.92 / 6.37	0.35	15.0
2			5	250											3.88 / 4.17	8.5	15.0
3			10	500											3.32 / 3.57	24.7	15.0
4			12	600											3.21 / 3.42	29.5	15.0
5			25	1250											2.73 / 2.93	43.7	16.0
6			75	3750											2.18 / 2.33	53.4	28.0
7			125	6250								↓	↓		1.92 / 2.10	56.1	44.0
8			1	50								1	-150		5.92 / 6.37	5.1	1.0
9			5	250											3.88 / 4.17	28.8	1.2
10			10	500											3.32 / 3.57	37.9	1.8
11			12	600											3.21 / 3.42	39.7	2.2
12			25	1250											2.73 / 2.93	46.1	5.0
13			75	3750											2.18 / 2.33	53.5	19.0
14			125	6250	↓							↓	↓		1.92 / 2.10	56.1	36.0
(4)	Wall Thickness / Radius		12	600	1/50							15	-10		3.21 / 3.42	29.5	15.0
15				300	1/25										3.72 / 3.99	30.2	15.0
16				120	1/10										4.63 / 4.98	31.4	15.0
17				36	1/3										6.57 / 7.07	34.0	15.0
18			↓	12	1/1										10.09 / 10.92	38.3	15.0
(5)			25	1250	1/50										2.73 / 2.93	43.7	16.0
19				625	1/25										3.16 / 3.39	44.9	16.0
20				250	1/10										3.88 / 4.17	46.5	15.5
21				75	1/3										5.25 / 5.65	49.1	15.5
22			↓	25	1/1							↓	↓		7.46 / 8.05	52.6	15.5
(11)	Temperature Changing Rate		12	600	1/50							1	-150		3.21 / 3.41	39.7	2.2
23												5	-30			37.5	5.5
(4)												15	-10			29.5	15.0
24												30	- 5			20.8	30.0
25												75	- 2			9.8	75.0
26			↓	↓								150	- 1		↓	5.0	150.0
(12)			25	1250								1	-150		2.73 / 2.93	46.1	5.0
27												5	-30			45.8	7.5
(5)												15	-10			43.7	16.0
28												30	- 5			39.7	30.0
29												75	- 2			29.6	75.0
30			↓	↓						↓	↓	150	- 1		↓	19.3	150.0
(4)	Total Temperature Change		12	600						385	150	15	-10		3.21 / 3.42	29.5	15.0
31										435	100	10			3.21 / 3.35	21.9	10.0
32			↓	↓						485	50	5			3.21 / 3.26	12.2	5.5
(5)			25	1250						385	150	15			2.73 / 2.93	43.7	16.0
33										435	100	10			2.73 / 2.86	29.6	11.5
34			↓	↓						485	50	5	↓		2.73 / 2.80	14.8	7.5
(25)			12	600						385	150	75	-2		3.21 / 3.42	9.8	75.0
35										435	100	50			3.21 / 3.35	9.3	50.0
36			↓	↓						485	50	25			3.21 / 3.26	7.5	25.0
(29)			25	1250						385	150	75			2.73 / 2.93	29.6	75.0
37										435	100	50			2.73 / 2.86	22.9	50.0
38		↓	↓	↓	↓	↓	↓	↓	↓	485	50	25	↓	↓	2.73 / 2.80	13.4	25.5

TABLE 3-2 PARAMETRIC STUDIES FOR THERMAL TRANSIENT STRESSES OF STRAIGHT PIPES

Problem NO.	Parameter	Material	Thickness (h) mm	Radius (inner) (R) mm	$\frac{h}{R}$	Inner Fluid	Fluid Velocity m/sec	Outside Thermal Condition	Initial Temperature Ti °C	Final Temperature Tf °C	Total Temperature Change °C	Duration of Trangsient Temperature Time sec	Temperature Changing Rate °C/sec	Pattern of Temperature Change	Heat Transfer coefficient Kcal/cm^2. sec. °C x 10^{-4}	Maximum Hoop Strcess kg/mm^2	Time of Maximum Stress sec
39	Fluid Velocity	SUS304	12	600	1/50	Na	0	Insulated	535	385	150	15	-10	Linear	0.202 / 0.217	8.5	19.0
40							1								0.927 / 0.995	21.2	15.5
41							3								2.15 / 2.30	27.4	15.0
(4)							5								3.21 / 3.42	29.5	15.0
42							10								5.51 / 5.91	31.4	15.0
43							100								34.2 / 36.9	33.8	15.0
44							4000								1000.0	34.2	15.0
45			25	1250			0.1								0.149 / 0.161	12.3	38.0
46							1								0.771 / 0.823	30.9	21.0
47							3								1.83 / 1.96	40.3	17.0
(5)							5								2.73 / 2.93	43.7	16.0
48							10								4.73 / 5.07	47.2	15.5
49							100								29.7 / 31.8	51.9	15.0
50							8000					↓	↓	↓	1000.0	52.9	15.0
(5)	Pattern of Temperature Rate						5					15	-10	Linear	2.73 / 2.93	43.7	16.0
51														Pattern A		43.4	14.0
52												22.5		Pattern B		41.0	19.5
53		↓							↓		↓	30	↓	Pattern C	↓	38.8	26.0
(5)	Material	SUS304							535		150	15	-10	Linear	2.73 / 2.93	43.7	16.0
54		2¼ Cr-1Mo A														35.8	16.5
55		2¼ Cr-1Mo B							↓		↓	↓	↓		↓	31.4	16.0
56		SUS304							485		100	20	-5		2.80 / 2.93	28.3	21.0
57		2¼ Cr-1Mo A														23.2	21.0
58		2¼ Cr-1Mo B							↓		↓	↓	↓		↓	19.8	20.5
(5)	Temperature Dependancy of Material Properties	SUS304 as a function of temperature							535		150	15	-10		2.73 / 2.93	43.7	16.0
59		SUS304 at 535°C													2.73 / 2.73	37.3	16.0
60		SUS304 at 385°C													2.93 / 2.93	41.2	16.0
(54)		2¼ Cr-1Mo A as a function of temperature													2.73 / 2.93	35.8	16.5
61		2¼ Cr-1Mo A at 535°C													2.73 / 2.73	29.7	16.0
62		2¼ Cr-1Mo A at 385°C													2.93 / 2.93	30.7	16.0
(55)		2¼ Cr-1Mo B as a function of temperature													2.73 / 2.93	31.4	16.0
63		2¼ Cr-1Mo B at 535°C													2.73 / 2.73	26.6	16.0
64		2¼ Cr-1Mo B at 385°C	↓	↓		↓	↓		↓	↓	↓	↓	↓		2.93 / 2.93	25.9	15.5
(1)	Steady State Analysis	SUS304	1	50		Na	5		535	385	150	15	-10		5.93 / 6.37	0.35	15.0
(2)			5	250											3.88 / 4.17	8.5	15.0
(3)			10	500											3.32 / 3.57	24.7	15.0
(4)			12	600											3.21 / 3.42	29.5	15.0
(5)			25	1250											2.73 / 2.93	43.7	16.0
(6)			75	3750											2.18 / 2.33	53.4	28.0
(7)			125	6250		↓	↓	↓	↓	↓	↓	↓	↓	↓	1.92 / 2.10	56.1	44.0
65			1	50												35.7	
66			5	250													
67			10	500													
68			12	600													
69			25	1250													
70			75	3750													
71		↓	125	6250	↓	↓										↓	