Visualization Method for Vapor Film Collapse Mode on Liquid Quenching in Group processing

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4TH/JAN/2021 FROM CRYSTAL BRIDGE, ASAHIKAWA, JAPAN

Agenda

- ✓Background
- ✓Heat treatment deformation due to cooling variations within a single piece
- ✓Cooling analysis method for group processing
- ✓CFD result
- ✓Cooling calculation result
- ✓Conclusion

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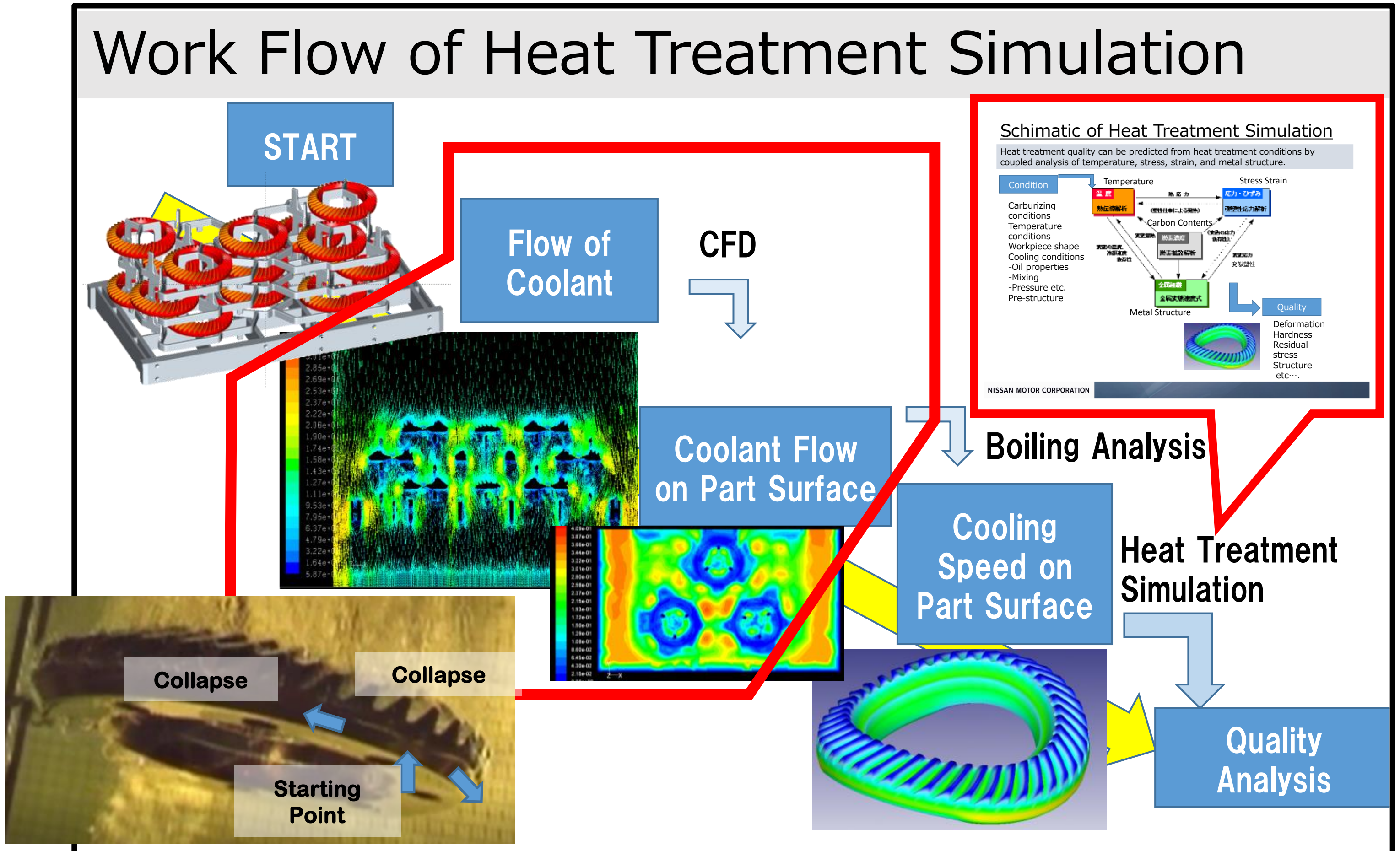
Relationship between Cooling State and Heat Treatment Deformation



In oil quenching, uneven cooling of the surface due to the collapse of the vapor film affects heat treatment deformation.

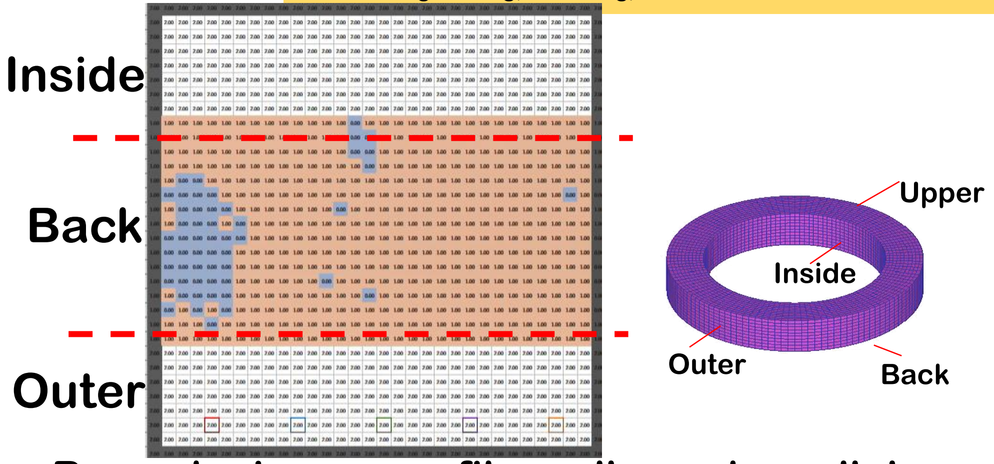
Influence of thermal boundary conditions on the results of heat treatment simulation, Tsuyoshi Sugimoto, Dong Ying Ju, Materials Transactions 59(6) 950-956 2018

To solve cooling stage (vapor blanket stage, boiling stage, and convection stage on the part surface) is so important to solve heat treatment deformation

Cost due to complex shape and condition is expensive

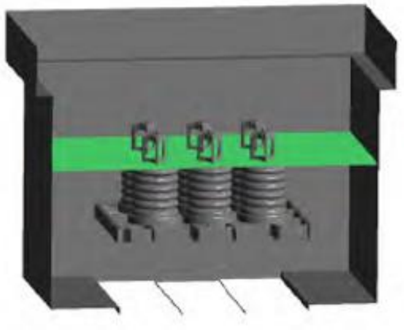
Cooling analysis using low-dimensional cellular automaton method

Visualization of vapor film collapse mode during unsteady boiling on oil quenching by using cellular automaton simulation, Tsuyoshi Sugimoto, 27th International Federation for Heat Treatment and Surface Engineering, Saltzburg, Austria 2022

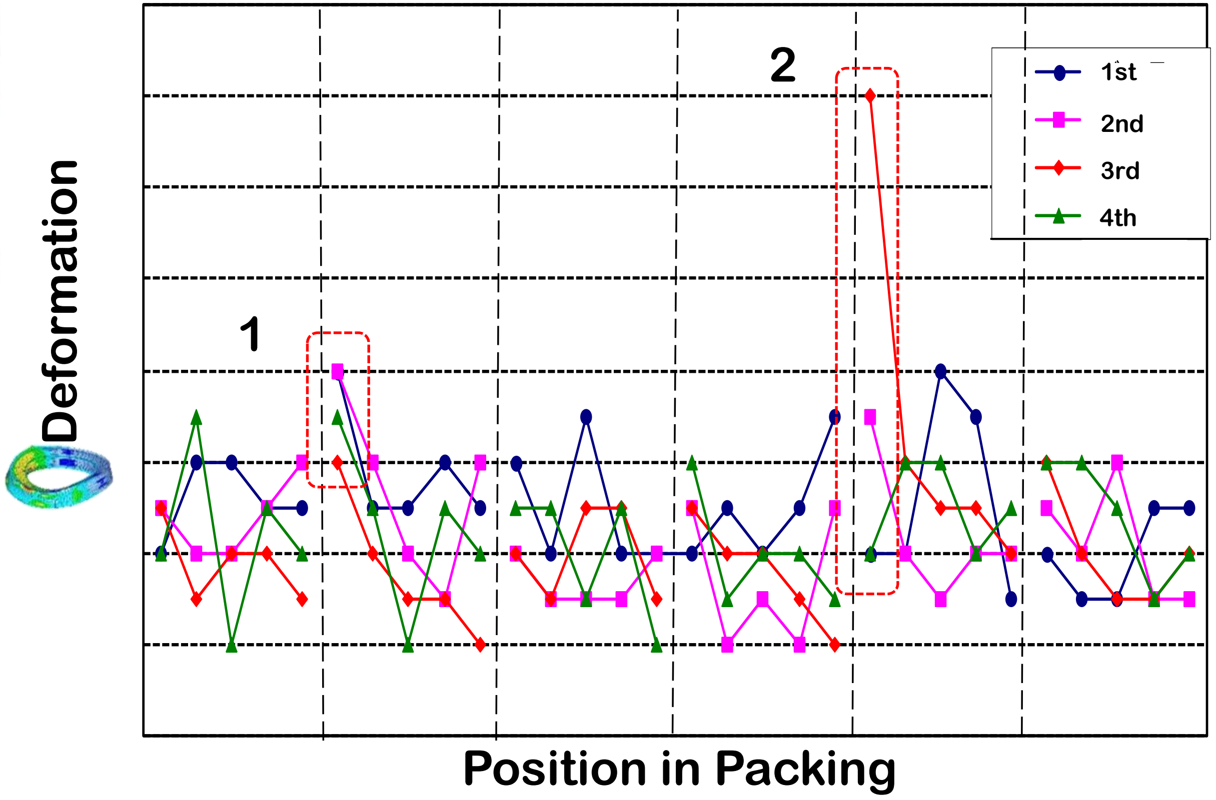


Reproducing vapor film collapse by cellular automaton

Heat Treatment Deformation in Group Processing



Load Setting



Heat treatment deformation of group packages is occurred as followed.

1 Constant deformation is large at a specific location

2 Repeated deformation variation increases at a specific location

Repeated changes in heat treatment deformation (experimental)

Classification of heat treatment deformation

Note: In reality, it is not that simple because there are interactions.

		Factor		
		Shape of Object	Repeated instability of boiling cooling	Flow pattern
Deformation	1 Constant Large	◎	○	◎
	2 Repeated Variation	◎	◎	○
	Simulation Method	DEFORM-HT etc.	Vapor film collapse simulation (IFHTSE2023)	This Report

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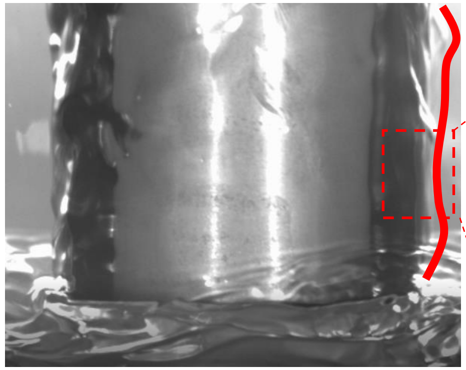
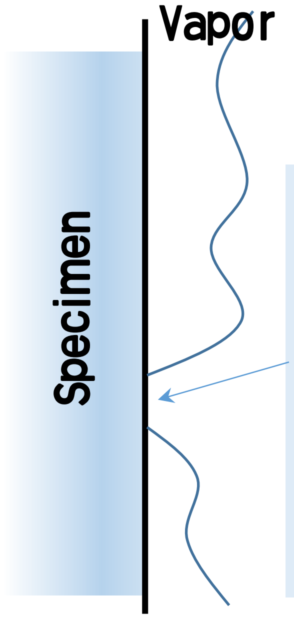
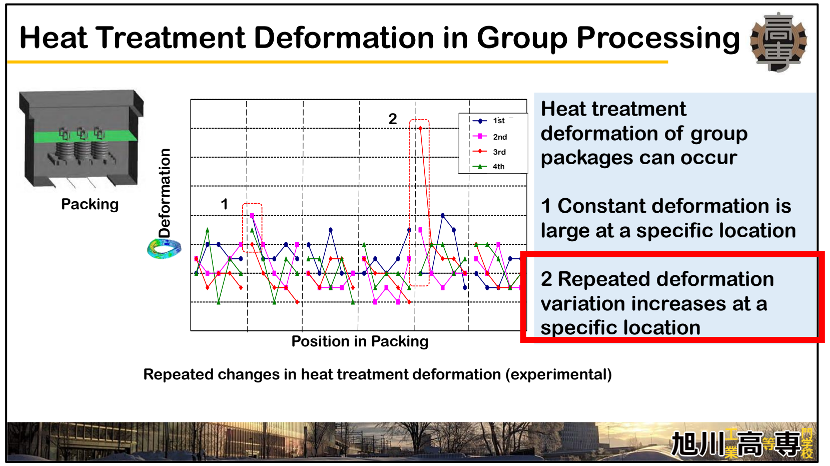
Vapor film vibration causes cooling variations



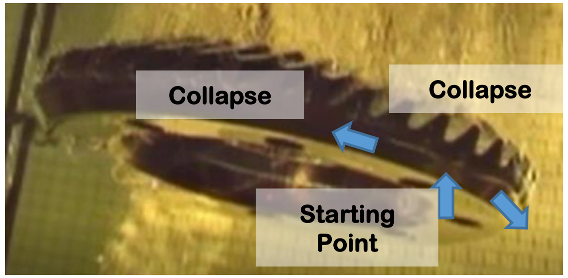
Vapor film variation



The vapor film vibration causes the vapor film thickness to become thinner, and the vapor film begins to collapse when the quenchant reaches the object surface.



By reproducing the vapor film vibration as a wave, uneven cooling will be reproduced.



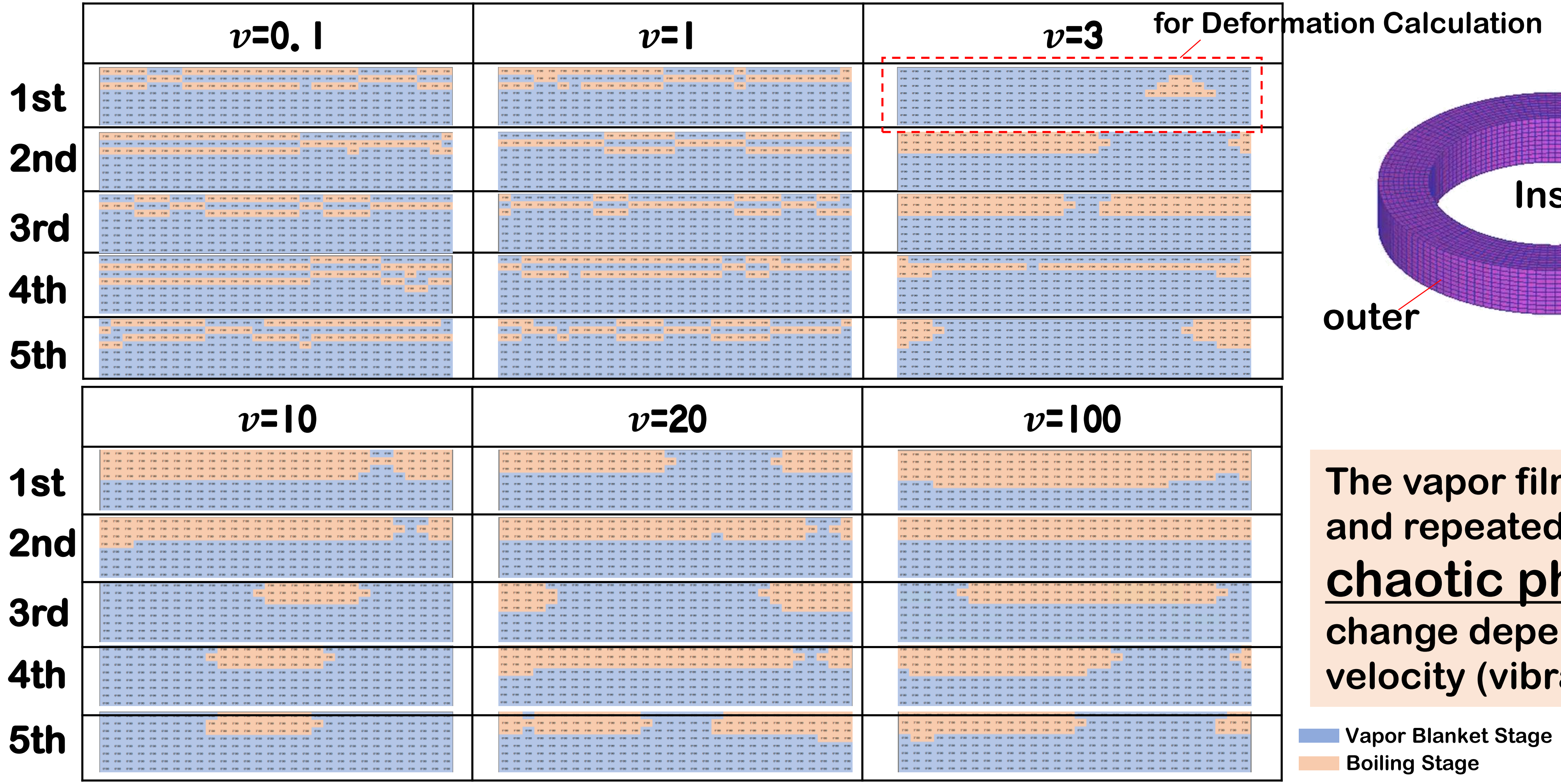
Wave Function: $\frac{1}{v^2}\frac{\partial^2 u}{\partial t^2} = \nabla^2 u$ ··Eq. (4)

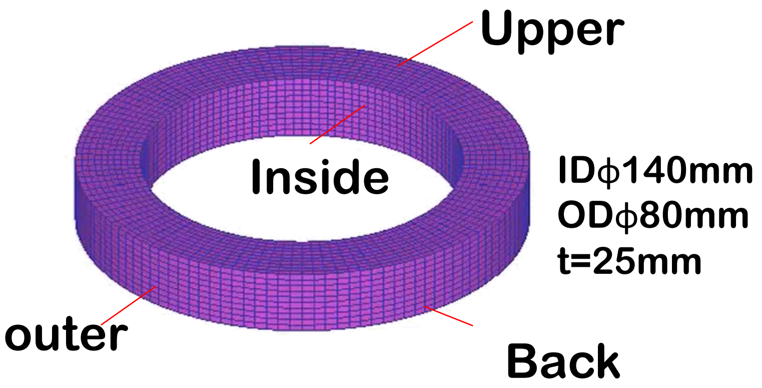
v : Phase velocity
u : Film thickness
t : time

+

External excitation with random factors: r

Heat treatment deformation calculation for a single piece -Change in vapor film collapse-

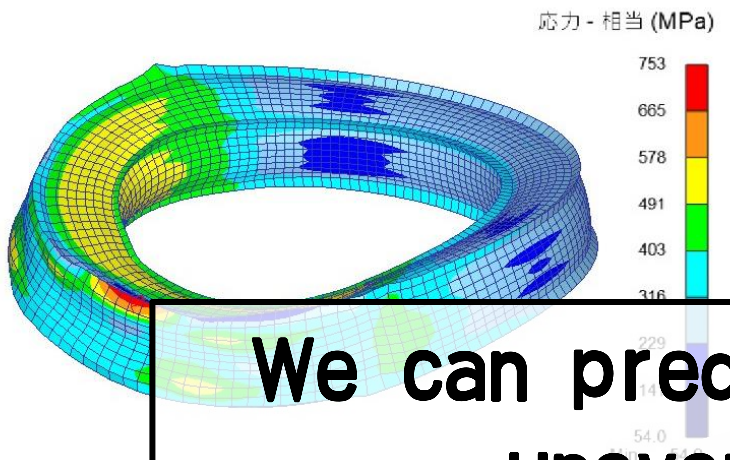


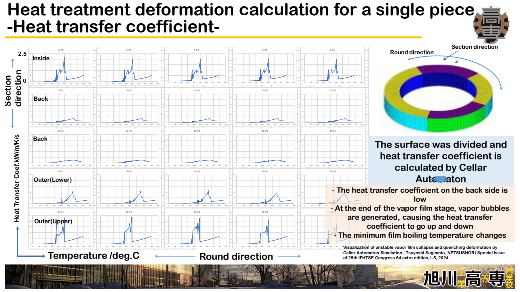


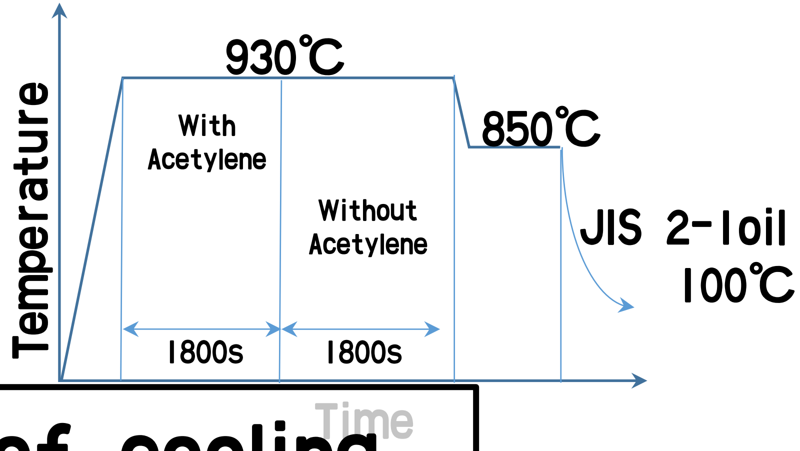
The vapor film collapse pattern and repeated changes are <u>**chaotic phenomena**</u> that change depending on the phase velocity (vibration pattern)

Repeated changes in the collapse of the vapor film at the periphery when v is changed

Heat treatment deformation calculation for a single piece -Deformation-

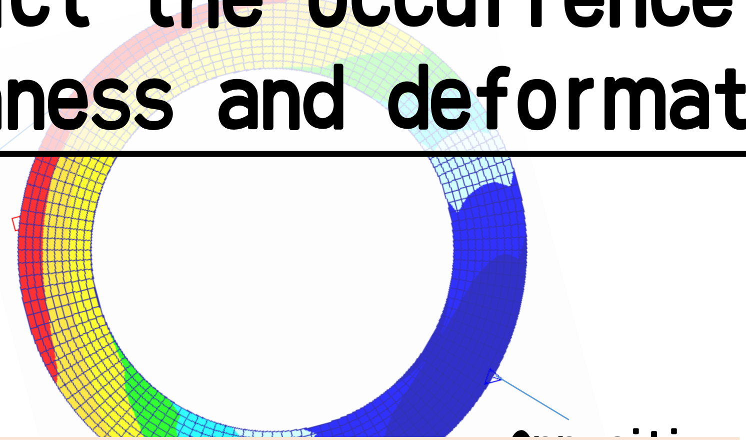






Heat Treatment Condition

We can predict the occurrence of cooling unevenness and deformation.



Max Deformation 0.3mm
(The rear surface flatness under the same conditions was 0.3 mm.)

Simulation Conditions

Solver	SFTC DEFORM-HT ver13
Nodes	14520
Elements	12000
Coating Mesh Size	0.1mm
Element Shape	Hexagon

- The calculations are generally quantitatively accurate.
- Thermal deformation caused by initial temperature unevenness continues to have an effect until the end.

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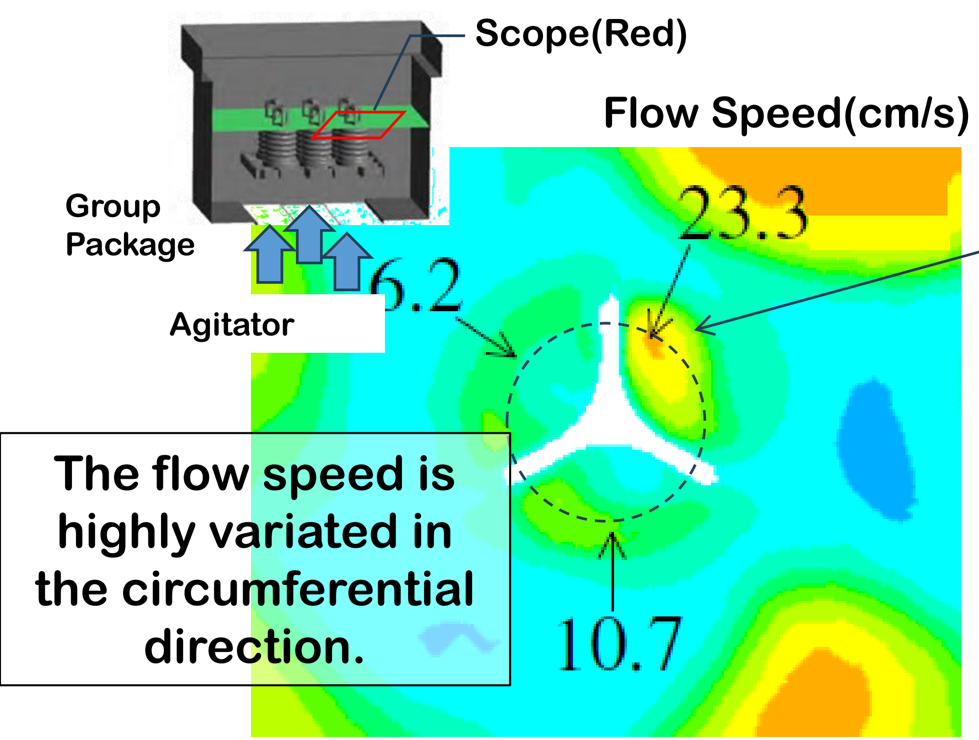
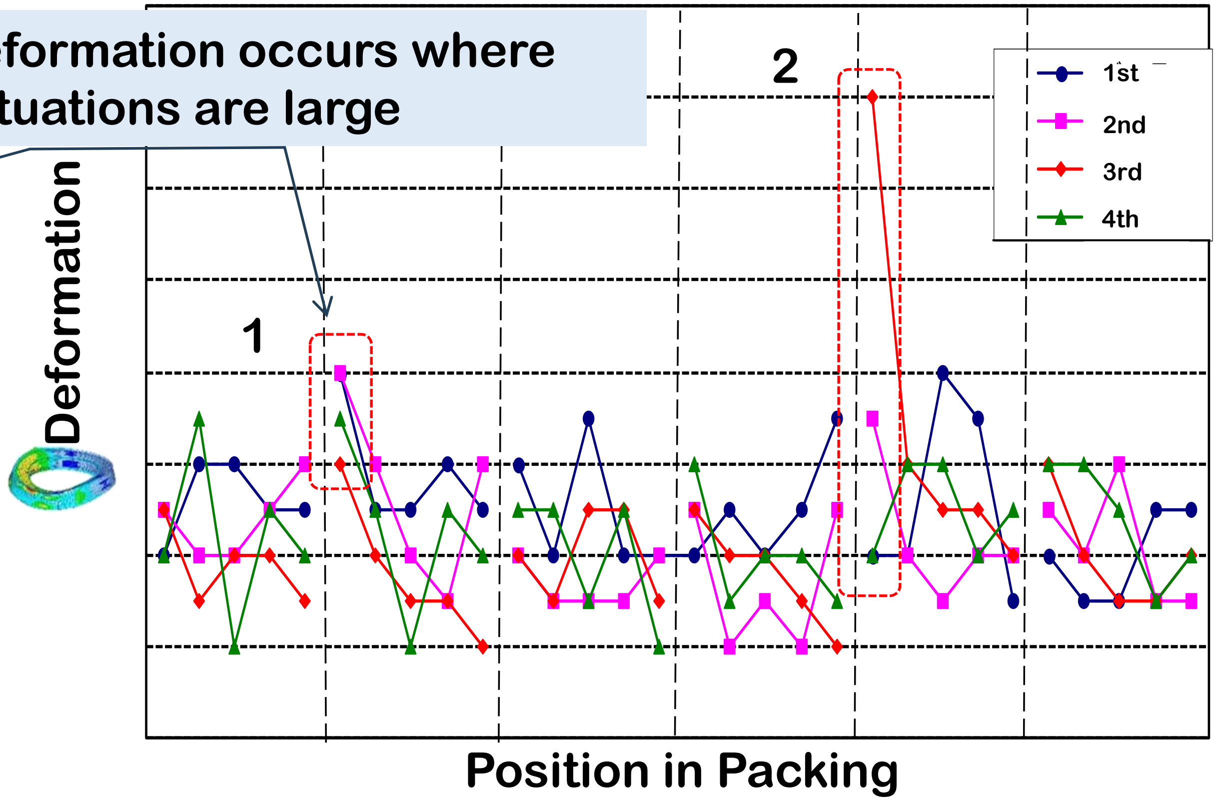
Heat treatment deformation in group packaging



Oil flow velocity distribution within the red frame during ring part quenching

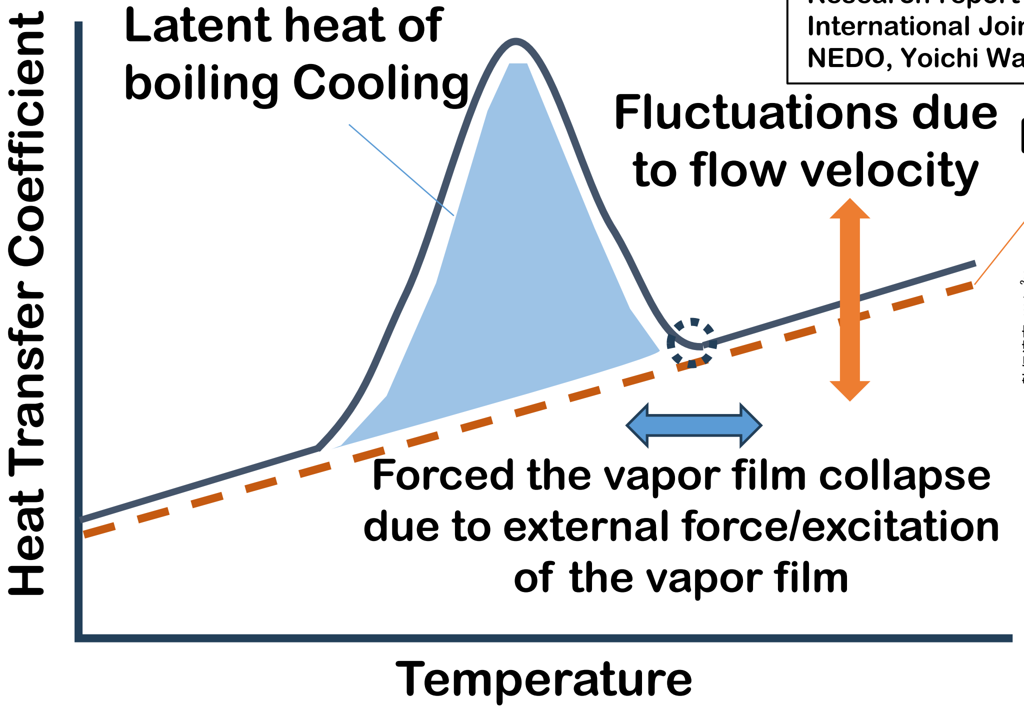
Large deformation occurs where flow fluctuations are large



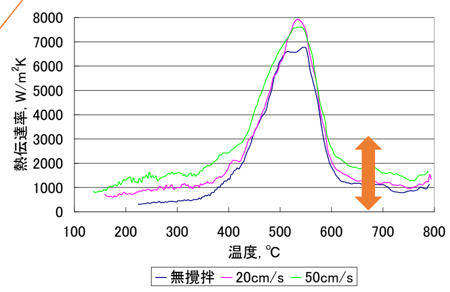
Repeated changes in heat treatment deformation (experimental)

Is it possible to solve the Heat Treatment Deformation of Group process by solving the interaction between fluid and cooling

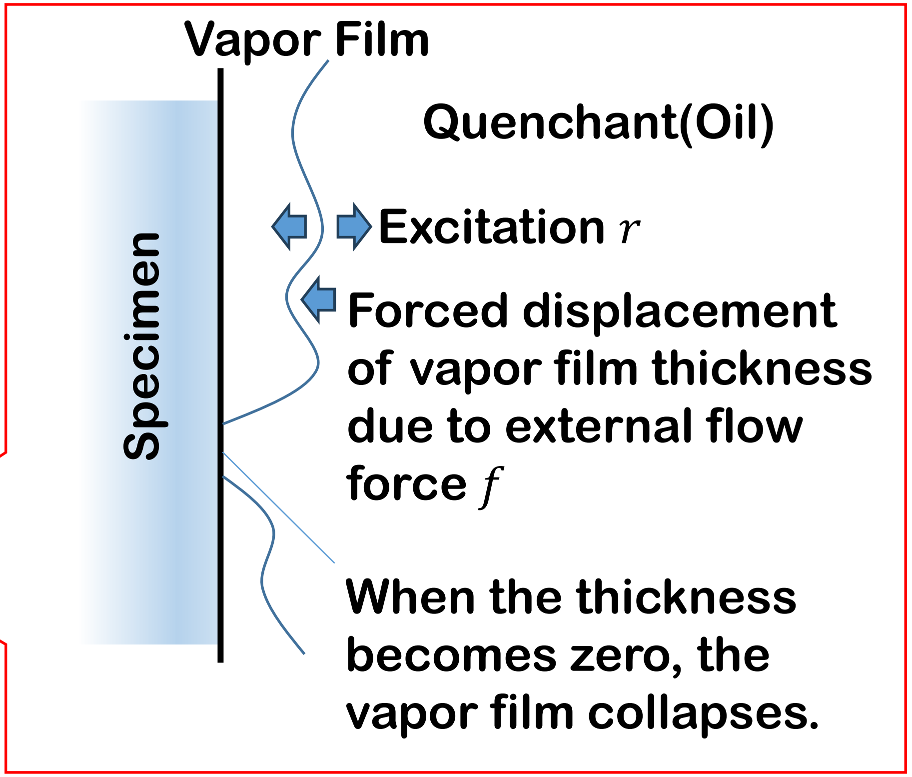
Interactions of Fluid flow and Boiling Film Collapse



Research report on the 2002 IMS International Joint Research Project of NEDO, Yoichi Watanabe et al., 2002



Research on the vapor film collapse process in triggering of vapor explosion phenomenon, Takahiro Arai, 2010



Hypothesis of Flow Effect on Boiling Cooling

Changes in the vapor film thickness due to flow velocity and flow, and changes in the vapor film vibration are incorporated into the vapor film vibration equation.

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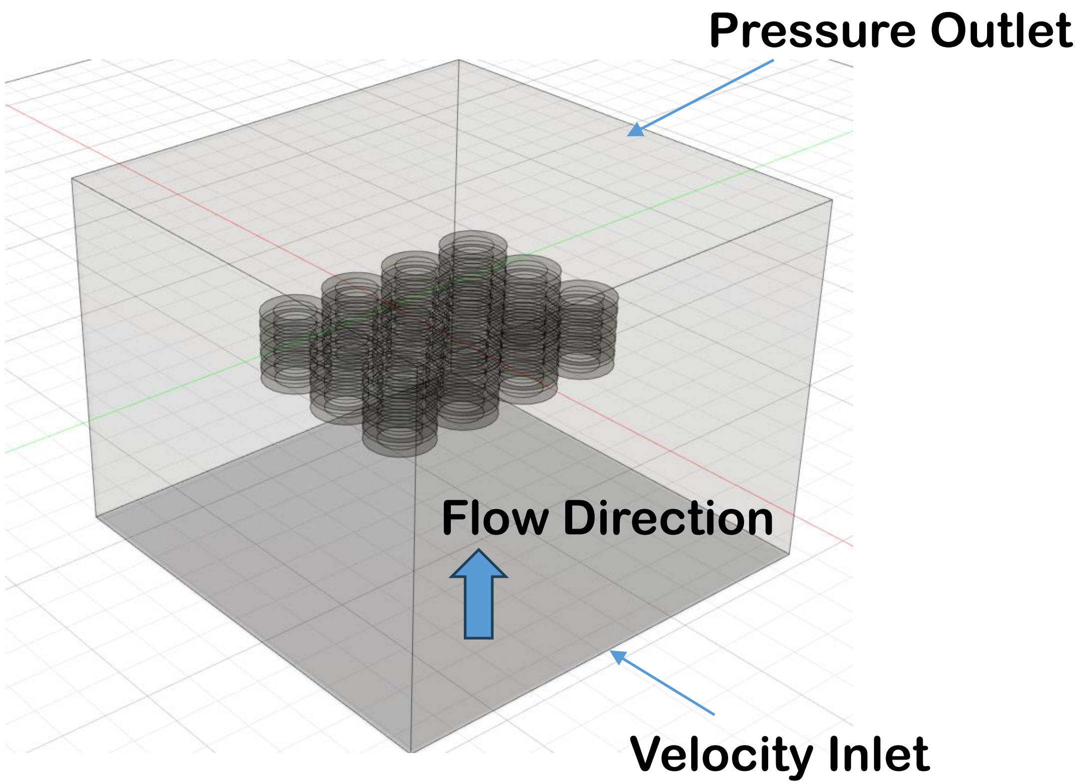
CFD conditions

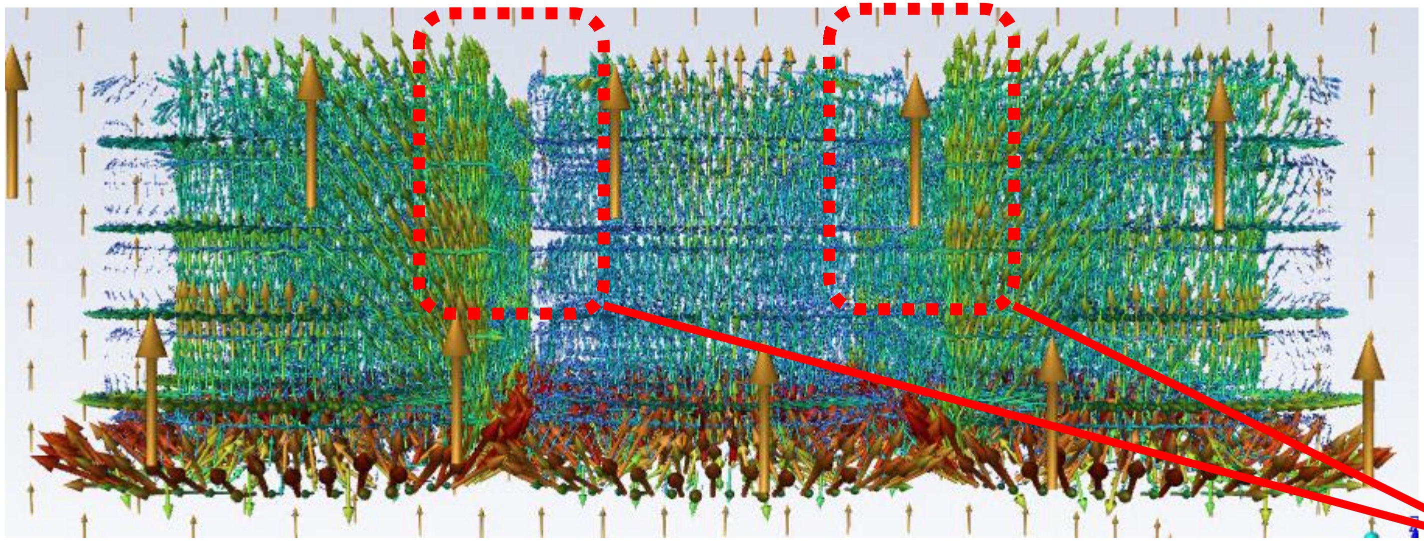


Solver	ANSYS Fluent 2023
Quenchant Density[kg/m^3]	800
Quenchant Viscosity[kg/m/s]	0.8m/s
Inlet Velocity[m/s]	0.8m/s
Outlet Pressure[Pa]	0
Flow Model	Laminar
Mesh number	313,567
Target maximum cell size[mm]	3mm
Target minimum cell size[mm]	35mm

Model: ϕ180mm(outer), ϕ100mm(inner) x t=35mm
Process Load setting: 3 x 4 x 7 pieces
Area size: 1200 x 1200 x 1000 (mm)

Because this study aims to easily solve the cooling of a group processing, a simple calculation model is set up. The free surface on the upper surface, the swirling flow due to agitation, the temperature, etc. are ignored.

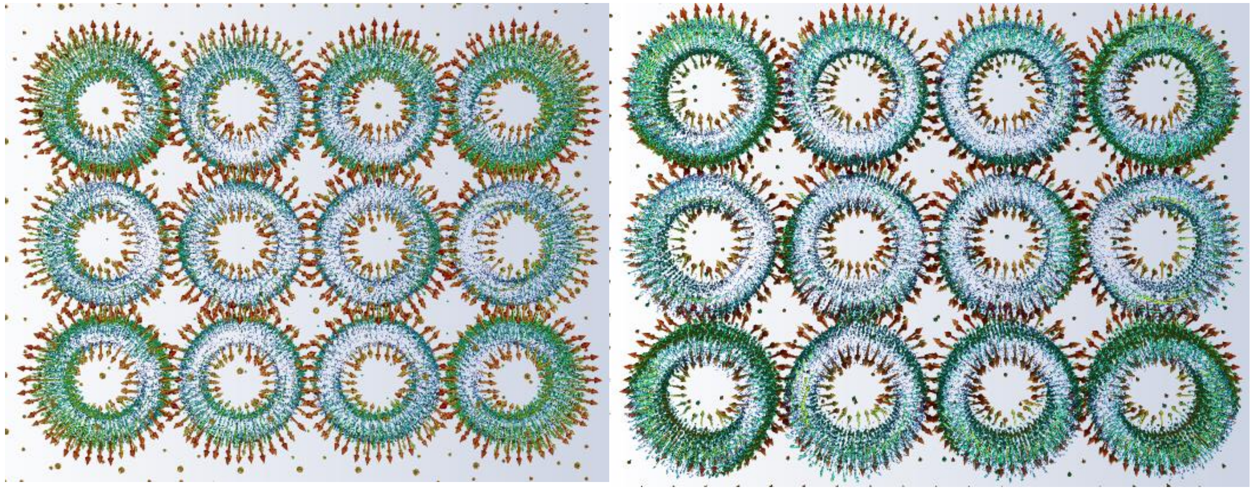
CFD results -Flow State-



2.0

0.0

Velocity magnitude[m/s]



The flow rate is faster in areas where the gaps between parts are narrow.

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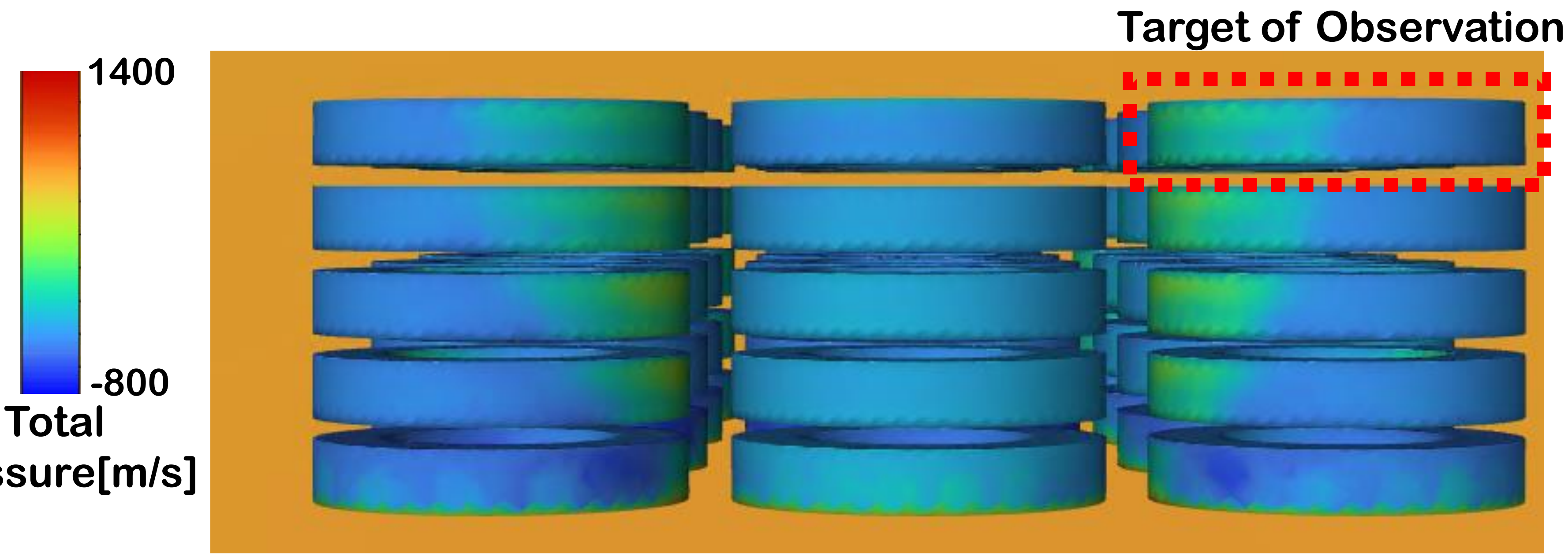
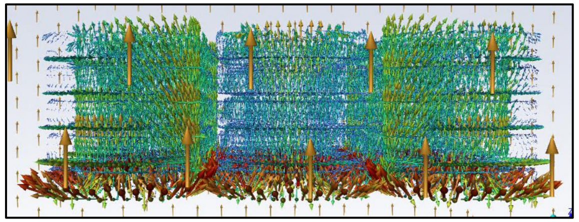
Estimation of external force acting on vapor film





In areas with high flow speeds, strong forces act on the surface of the parts.

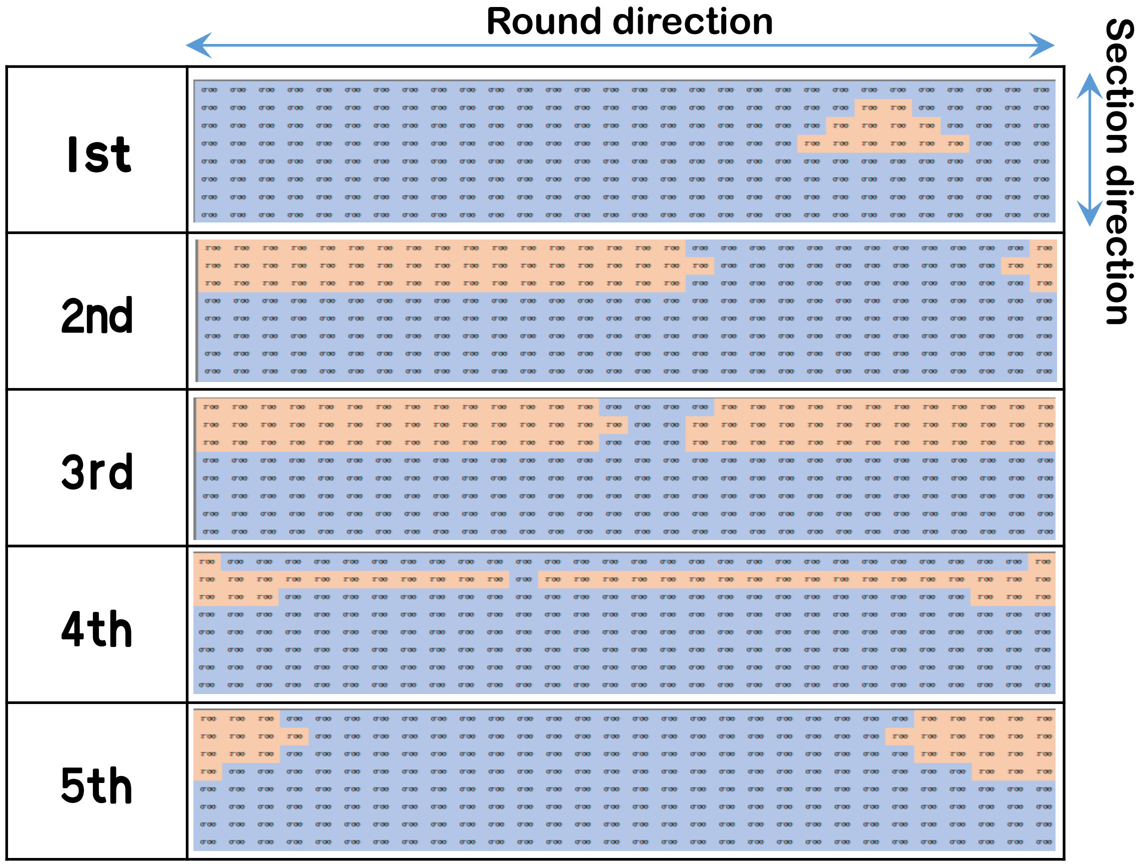
4.000	4.000	4.000	4.000	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.000	4.000	4.000	4.000	4.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000
5.000	5.000	5.000	5.000	3.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	3.000	5.000	5.000	5.000	5.000

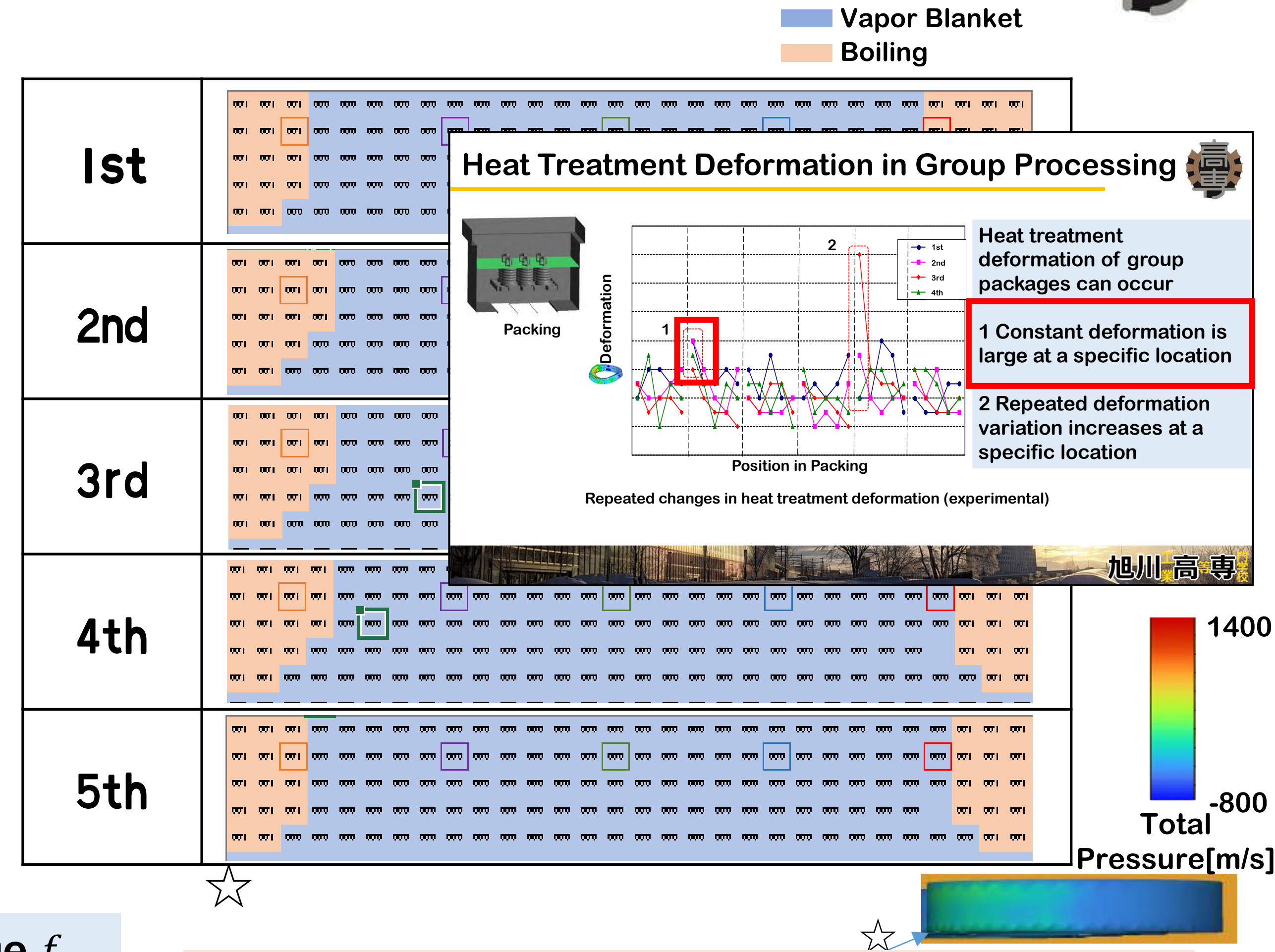
f: Film thickness reduction

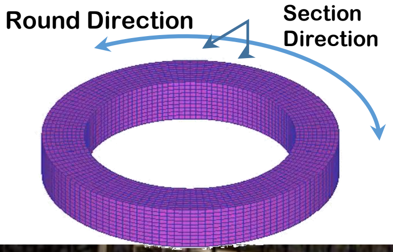
1	0.2
1	
1	
0	
0	
0	0

Definition of vapor film thickness reduction

Vapor film collapse reflecting pressure fluctuations in group processing







By applying a forced film thickness change f to the area with large total pressure, the vapor film collapse was stabilized.

Stable and large cooling unevenness (heat treatment deformation)

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Conclusion

<u>From the results</u>

By incorporating phase velocity v (oil properties, scale) and vapor film excitation force f (pressure, etc.) and coupling with steady-state fluid analysis, we were able to perform cooling analysis of group processing

<u>Future</u>

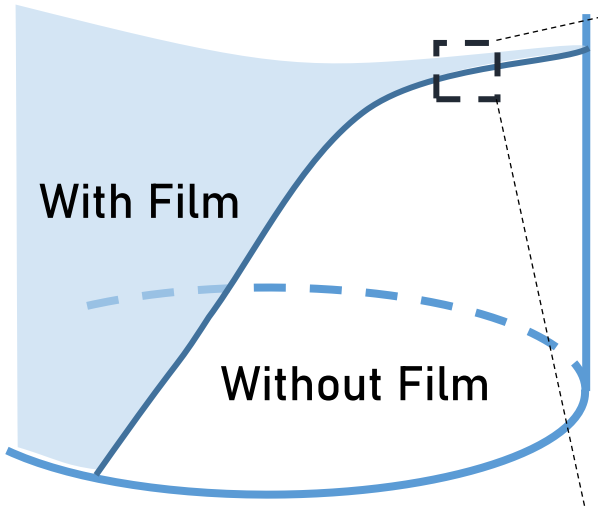
Since many phenomena that change the steam film thickness have been reported, we will experimentally extract and incorporate important parameters, especially in "collective quenching"

Quantitative verification of repetition and variation within the package

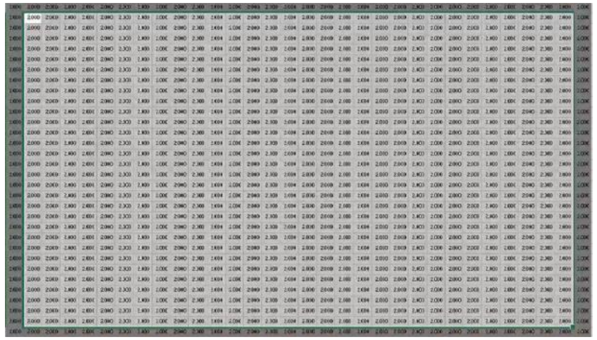
This research was partly supported by JSPS Grant No. Research JP21K14061 "Quenching Simulation Reflecting Manufacturing Variations Using Low-Dimensional Cellular Automaton Method"

END

Basic Formula



Collapse of Vapor Film



セルオートマトン法による蒸気膜崩落

Wolframによる相変態モデル

注目セル

	S_4^t	
S_2^t	S_0^t	S_1^t
	S_3^t	

相変態：ノイマン近傍
（周辺セルから弱い影響を受ける）

T_8^t	T_4^t	T_5^t
T_2^t	T_0^t	T_1^t
T_3^t	T_3^t	T_7^t

温度：ムーア近傍
（周辺セルから強い影響を受ける）

S_i^t：相

0：蒸気膜段階
1：沸騰段階
2：対流段階

t:時刻
i:位置

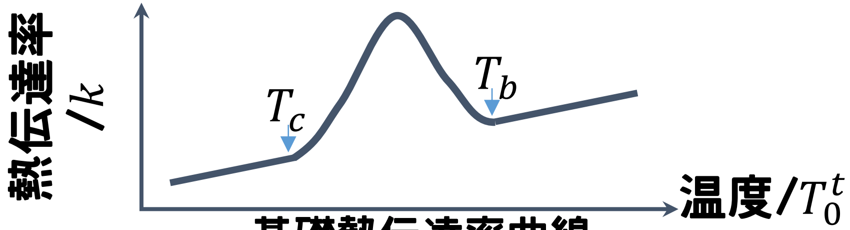
T_i^t：温度

Wolfram, S., *A New Kind of Science*, Wolfram Store, 2007

サブクール沸騰モデル

相変態：
$S_0^t = 0$ and $\sum_i S_i^t \geq b$ and $T_0^t \leq T_b$ then $S_0^{t+1} = 1,\ T_0^{t+1} = T_0^t - \alpha$ ‥式.(1)
$S_0^t = 1$ and $\sum_i S_i^t \geq c$ and $T_0^t \leq T_c$ then $S_0^{t+1} = 2$ ‥式.(2)

温度：
$$T_0^{t+1} = T_0^t + \left\{\frac{1}{6}\left(T_1^t + T_2^t + T_3^t + T_4^t\right) + \frac{1}{12}\left(T_5^t + T_6^t + T_7^t + T_8^t\right) - k\cdot\left(T_e - T_0^t\right)\right\}$$ ‥式.(3)



基礎熱伝達率曲線

α：潜熱
b，c：形状因子
T_e：冷媒温度
k：熱伝達率