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Heat transfer properties for RMI (reflective metal insulation) thin plate designs

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1. Introduction

Recently, Nuclear power plants are going to solve various safety issues such as post-actions of LOCA accident. In this point, RMI(reflective metal insulation) is recommended item to replace the existing insulations (glass fiber) for complete blocking of debris sources[1]. These are mainly related to corrosion & chemical resistance of stainless steel material. RMI also has to secure the similar thermal insulation performance compared to existing insulation. In order to verify the RMI thermal performance likewise conductivity and transference, we conducted on finding the major mechanism of RMI heat transfer and maximizing thermal properties by design various types. We had found that there is little convection flow under slight small air gap with less than 10mm thickness [1]. Small air gap only allow laminar flow between the plates that means turbulent flow is ignorable across the air space. So conduction and radiation flow is dominant to decide RMI thermal property. Previous work also reviewed the feature about conductive loss at RMI module structure. It is instinctively connected with metal contact and metal thickness, so that we determine the design concepts for smaller metal contact. In this point, radiation heat transfer is to be the most important factor to maximize insulation performance of nuclear components. In this paper, I would like to show radiation effect according to the RMI thin plate designs by comparing experimental and CFD simulations.

2. Methods and Results

Various designs about RMI thin plates are related with forming shape, forming direction, stacking methods, air-gap thickness. Based on the flat plate as for basic model, it was reviewed RMI designs from various perspectives for thermal flow and values.

2.1 Theoretical approach for RMI forming shape and designs

It would be written that radiation equation for flat plate is simply function of opposite dimension (m^2) and temperatures (K) for two opposite face. In fixed temperature, number of flat plate and emissivity is key factor to minimize the heat loss through the insulation medium [2-3]. But it is so difficult to set up the flat type design due to stacking method, and forming design by machine works is recommended for construct the RMI designs. Form plate('we called embo type'). Embo type design has additional design factor about complex shape of concave and convex or not. Each shape is classified with distinct relation function and shape factor graph. Whereas flat type, there is only one way term of $F_{1\rightarrow2}/F_{2\rightarrow1}$, other shapes(triangle, cylinder, etc) are comprise of various heat transfer direction[1]. For RMI Embo design, It has a lot of geometry to make-up the shape and difficult to calculate exact shape factor value. In this hand, I want to use CFD calculation for various embo designs and other like that.

2.2 Experiment and review about designs of RMI plates

Thermal conductivity for RMI thin plate designs is measured by using the GHP456 titan model to review the CFD analysis result. Basic design for test is flat type with 12 plates and comparison target for simulation is embo type model with 1~2 plates. Experiment and CFD analysis are same model dimension and heating/cooling condition. Detail conditions are as below;

- Mean temperature : 200 ^{o}C
- Model dimension : 150mm(W, L), 90mm(H)
- Thin plate : SUS304, 0.06mm
- SUS304 plate emissivity : 0.12
- Number of plates : 12 EA(air gap ~7mm)

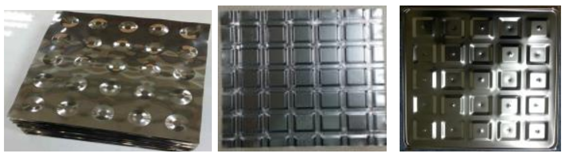
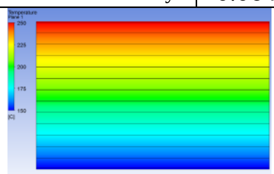
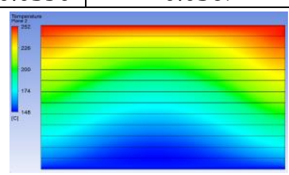


Fig. 1. Various RMI design and types

Table I: Experiment and CFD review

W/m-K	Test	CFD	
		Laminar	Laminar+radiation
Thermal conductivity	0.0641	0.0390	0.0567
 CFD_laminar		 CFD_laminar+radiation	

Laminar flow through the RMI design of flat type means that there is only the amount of air conductivity with uniform temperature distribution. Radiation option activates more heat transfer compared to laminar flow likewise other temperature contour. Difference between test and CFD considering the radiation seems to get the heat loss at the sample side[4]. Real test has glass-fiber insulation around sample. So this allows reliability of design reviews by CFD simulation about RMI embo designs.

2.3 Analytical review of various RMI designs

We reviewed the 3-D shape RMI design such as embo depth, embo direction, stacking method. Because previous chapter already covered reliability about flat type, we have started insulation performance review from flat type to other embo type design. In order to minimize the simulation error due to complex and large model, we choose the simple model with 1 or 2 plates. Below figure is model and mesh condition with more than 100 million about 3mm embo depth and 2 plates.

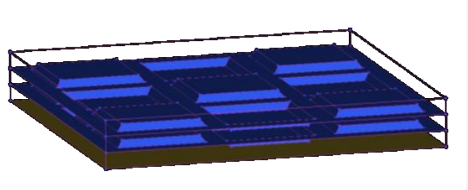


Fig. 2. RMI modeling and CFD mesh shape

Air gap is smaller than 10mm, so that convection factor is neglected and turbulent model is not accepted. And radiation term is DT model that is commonly used at the insulation part. CFD simulation is carried out various cases that related with embo depth, direction, stacking as below table.

Table Ⅱ: CFD simulation case

Case	Depth(mm)	Direction	Stacking	# of plates
Factor	3, 6	Two way	Normal opposite	1, 2

We have intended that embo depth is means of heat transfer starting point, direction is of fabrication, stacking is of heat transfer contact. Starting from flat type with only 1 plate, we review the above cases about thermal conductivity.

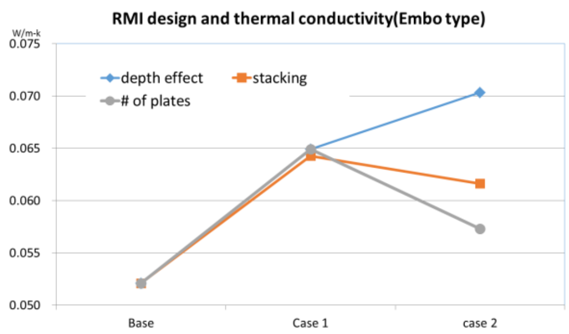


Fig. 3. CFD simulation result about each case and thermal conductivity

It is confirmed from the CFD simulation results that large depth is sensible to heat loss to cold part, and different air gap along the all surface is more prefer due to opposite stacking shape, and it is need to increase the number of plates. Below model is final embossing type design.

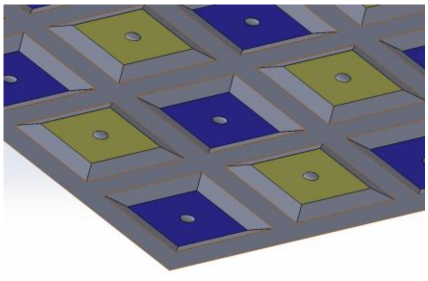


Fig. 4. Optimized RMI thin plate design for embo type

3. Conclusions

This paper covered thermal insulation effect of RMI designs about radiation heat transfer by test and CFD method. Thin plate shapes as of main key factor to determine RMI performance are reviewed. CFD simulation which is qualified by GHP test with error range shows that embossing type is preferred to apply to industry practically due to thermal conductivity. It is need to have the 3mm embo depth, two way direction, opposite stacking under resist the heat transfer across the multi-layers.

ACKNOWLEDGMENTS

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