가정용 냉장고의 냉동실 내벽의 비드가 케비넷 변형에 미치는 영향
The Effect on Cabinet Deformation by Bead of Inner Case

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1. Abstract

In the manufacture process of refrigerator cabinet, polyurethane (PU) liquid firstly is injected between outer plate and inner case in high temperature about 40℃, and PU foam is generated and solidified to the room temperature. There will be great residual stress in the PU foam, especially at the corners after the whole refrigerator is completely assembled. The stress condition will become more complicated under operating condition because of the large temperature difference between the freezing room and outer plate. And also, there are great differences of properties for plastic and steel which would cause different deformation under temperature gradient. The steel outer plate would expand compared to the PU foam or ABS material under operation condition, which induces a thermally bowing deformation in the refrigerator cabinet. The objective of this paper is to design an optimum bead structure or to use reinforcement in the refrigerator except for improving material properties in order to decrease the deformation.

2. FEM analyses

2.1 FEM modeling

In this paper, we used ANSYS V12.0 software and took a simplified FEM modeling of a LG refrigerator, in which we didn't take any detail parts into account except for beads. Outer plate material is steel, inner case is ABS_RS656H plastic; a layer of foam is inserted between the steel and the plastic liner which acts as thermal insulation and provides structural rigidity to refrigerator cabinet.

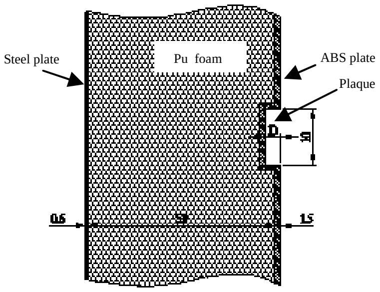

Fig. 1 Refrigerator sidewall structure

Figure 1 shows the section of side wall in freezing room, thickness of component is shown in Table 1. The bead is designed as 187×13×D according to the actual refrigerator. The effects of bead depth which is an important variable from 0mm to 4 mm (D=0, 1, 2, 3, 4 mm) are investigated. There are eighteen beads on either side of freezing room wall as shown in the Fig 2.

We assigned shell element, solid element to different components of modeling as shown in Fig 3.

Fig. 2 Beads on sidewall of freezing room

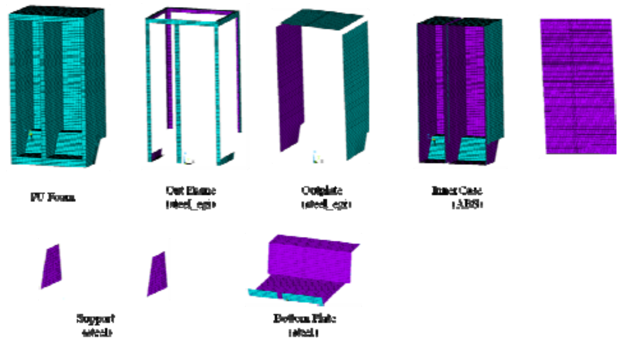

Fig 3 FEM modeling for each frame

2.2 Analysis condition

Usually, under operation condition, the room temperature is about 20℃, temperature in freezing and refrigerating room is respectively -18℃ and 3℃.

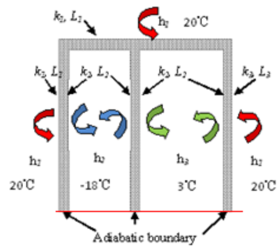

Fig . 4 Analysis condition

Heat transfer coefficient for outer space, freezing room and storing room is respectively:

Table 1 Parameters for analysis

	Plate thermal conductivity(J/m/K/sec)	Plate thickness(mm)
Steel	$k_1=45$	0.6
ABS	$k_2=k_3=0.0206$	1.5

Material propertied are derived from the test data in LG company and reference [1]. Convective heat transfer coefficients are $h_1=3W/m^2k$, $h_2=22W/m^2k$, $h_3=8W/m^2k$, and the equivalent convective heat transfer coefficient could be calculated by the following method:

$$h_{F.Inner}=\frac{1}{R_{F.inner}}=\frac{1}{\frac{1}{h_3}+\frac{L_2}{k_2}}=\frac{1}{\frac{1}{22}+\frac{0.0015}{0.0206}}\approx 8.5$$

2.3 FEM analysis process

2.3.1 Thermal analysis

Before taking a structure analysis for the FEM modeling, it should make clear how the temperature distributes in the cabinet, then, we put temperature load into structure analysis.

Solid 70 of element type in ANSYS has eight nodes with a single degree of freedom, temperature, at each node and has a 3-D thermal conduction capability which can also be replaced by an equivalent structural element (such as solid 45) in the following structural analysis process. In order to obtain optimal analysis data, we have to control the mesh quality as possible as we could, especially at sharp change position for temperature or stress.

2.3.2 Structural analysis process

There are several reinforcement structures on the actual refrigerator, so we have to redefine the element type, real constant and material property at relevant position. The FEM modeling in structural analysis is shown as below:

We fixed UX, UY, and UZ displacement for one of the four corner points in the bottom, and fixed the vertical displacement for the other three points. Then we loaded the temperature data which was derived from thermal analysis result and set reference temperature to 20℃, then solved the FEM modeling.

3. FEM analysis results

3.1 heat transfer analysis results

After analysis, we got all the temperature distribution results of the five FEM modeling in shown as Fig. 5. According to the results, it's almost the same under operation condition as shown in Table 2.

The bead almost do not have any effect in the heat transfer as shown in Table 2, and the maximum temperature difference occurs at the wall between outer plate and bead of freezing room.

Table 2 Temperature distribution with bead depth

	Bead depth (mm)				
T(℃)	0	1.0	2.0	3.0	4.0
Max.	31.921	31.922	31.928	31.928	31.928
Min.	-17.441	-17.441	-17.459	-17.459	-17.459

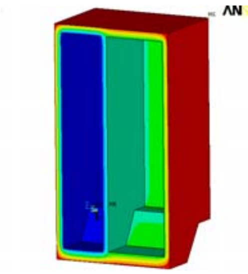

Fig. 5 Temperature distribution

3.2 structural analysis results

The results show a bowing deformation, and the maximum displacement is at the middle of the side wall of freezing room as shown in Fig. 6.

The horizontal directional deformation of side wall decreases with increasing depth of bead from 0 to 4mm, shown in Fig. 7.

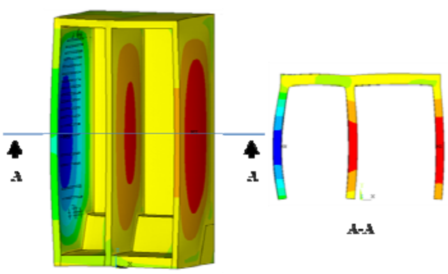

Fig. 6 Deformation of cabinet

We take three points on the modeling to compare the vertical stress on the wall of the five different bead types. As shown in Table 3 and Fig. 9, result shows that as the depth of bead increases, the vertical stress on the wall decreases as showing Table 3 and Fig 9. The beads provide increased surface area in the inner case to permit thermal expansion without deformation. Therefore the beads are very effective in the freezer compartment of a side-by-side refrigerator.

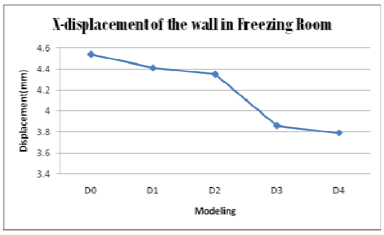

Fig. 7 Maximum deformation on the sidewall

Table 3 Vertical stress (kPa) on point A, B and C

Location In Fig. 8	Bead depth (mm)				
	D0	D1	D2	D3	D4
A	8.51	9.03	7.38	5.90	4.46
B	9.61	8.13	6.23	5.18	4.18
C	8.93	5.91	4.42	3.77	3.68

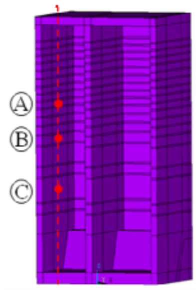

Fig. 8 Three points on the sidewall

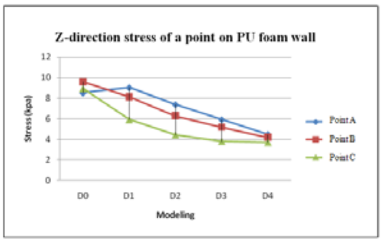

Fig. 9 Change of vertical stress of the three points

4. Conclusions

In this paper we designed a series of rectangular bead on the side walls of refrigerator, which would provide increased surface area and also increased the structural rigidity to resist wall deformation. The results show that as depth of bead increases, max imum deformation in horizontal direction and vertical stress on the side wall would decrease obviously. Therefore the plaques are very effective in the freezer compartment of a side-by-side.

However, for different refrigerator modeling, the further research on the effect of bead should be needed, for example, the number of bead on the side wall, the distance between every bead, the width, length and depth of bead, and also other bead shapes except for rectangular.

Reference

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