Design process to minimize roof surface defects by flexural function computed by Finite Element Method

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ABSTRACT

Appearance and exterior precision of the vehicle has become important factor as well as the performance. However curvature of the roof changes after oven process. In this study, Finite Element Analysis (FEA) is used to establish a method to predict the curvature change on the roof. Critical factor of curvature change on the roof is the thermal behavior of mastic sealer. Mastic sealer is a blowing agent which is applied between roof exterior panel and rails. Therefore the mechanism of the mastic sealer is considered to predict the curvature change accurately. Validation of the simulation model is performed by comparing the location and amount of the curvature change on the roof. In order to minimize the curvature change, Taguchi method is used. Total of eight factors are chosen for sensitivity analysis. In order to exclude the deformation due to residual stress after the oven process, it is selected as noise factor. Response is the maximum curvature change calculated by flexural function. Flexural function is introduced to distinguish absolute curvature that is not affected by the horizontal or vertical movement of roof panel. Flexural function calculates slope of plane normal vector for each nodes before and after the oven process. Total 18 cases are performed and as a result, length of each sealer, pitch of sealer, and location of rail are the most influential factors on the curvature change. Based on the result, optimized values are investigated. Using the optimum values, curvature change is reduced 12 percent.

Keywords: deformation on roof, thermal analysis, exterior curvature, optimum design

1 INTRODUCTION

In order to have global competitiveness in automobile market, appearance of an automobile must meet the customers' needs. In fast changing world, development time has become significant factor. The speed of this change is accelerated by the consumers' purchase trend in which they consider exterior, styling and convenience of automobile more seriously [1-2]. A traditional way of developing an automobile is dependent on the experience of engineers, especially in model development area. Mold manufacturing by trial-and-error process has reached limitations in the current situation where a short period of development time is demanded. Therefore, advanced automotive engineers as well as academia and research institutes have been trying to solve this problem [3] .

Moreover, companies have made efforts to meet the consumer's needs by building a high quality painting lines and designing a sophisticated exterior which corresponds to the performance of the vehicle. During these efforts, the exterior curve has become a significant factor.

The roof which is the widest planar curve among the part of automobile bodies is core part and requires flawless curve. In order to paint automobile body uniformly, electro-coating is done followed by baking in the oven for 20 minutes several times. This is called oven process. During the oven process, local deformation occurs on the surface of the roof. In order to judge the deformation, test has to be carried out at the end of the manufacturing process. Furthermore deformation that has already been occurred has to be judged only by a naked eye, so there is great loss on expense and time.

Until now, prediction of deformation on the roof using the Finite Element Method was not easy because there are only few researches published on the mechanical properties and foaming behavior of the mastic sealer. Mastic sealer containing blowing agent is spread between roof and rail for soundproof and dustproof. Hwang (2013) proposed a simple model that can be applied to the FE analysis for representing the behavior of materials with foaming characteristics [4]. In this study, the proposed model of materials with foaming characteristics will be applied to real product and investigate the behavior of micro deformation.

In this study, a method to predict the deformation quantitatively from the FE analysis result is proposed. First, thermal characteristic of mastic sealer is established. Established simulation model is validated by comparing the location and amount of the curvature change on the roof. In order to minimize the curvature change after the oven process, Taguchi method is used to find influential factors. Response of the Taguchi method is the change in curvature which is calculated by flexural function. Then chosen effective factors are optimized to minimize the curvature change. Significance of this study is that establish design process can be applied to further applications where curvature precision is important such as automobile hood, bumper, and so on.

2 THERMAL ANALYSIS METHODOLOGY

Mastic sealer fills the space between roof and roof rail by blowing and curing when it goes through high temperature oven process because it includes blowing agent. This characteristic of mastic sealer leads to change in curvature on the roof surface. Thus, the prediction of change in curvature by FEM using determined material models is needed. The surrounding temperature was set as 180 celcius which is the real process condition. It was heated for 20 minutes and cooled in room temperature for another 20 minutes. The model used for the analysis is shown in Fig.1.

Hwang (2013) have studied the characteristics of mastic sealer. In this study, blowing agent models proposed by Hwang is used. In this chapter, validation of reliability for predicting the deformation using mastic sealer model is done. Heat analysis applying determined coefficients to the realistic model and simple beam element were compared. Comparing these two cases, the deformation occurred only in the realistic model as shown in Fig.2. This indicates that the reliability of predicting deformation decreases when mastic sealer is not properly represented. Also it will be impossible to systematically design a roof with minimize curvature change. Therefore, heat analysis that considers the material behavior of mastic sealer is used.

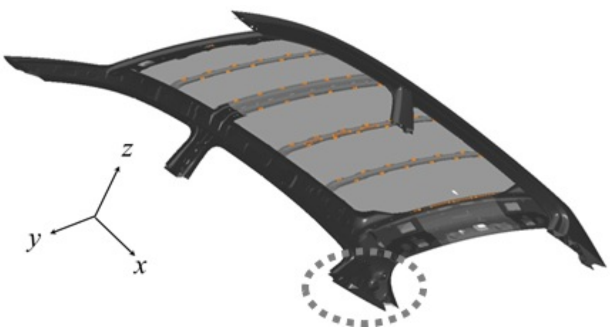


Figure 1: Geometric modeling of roof

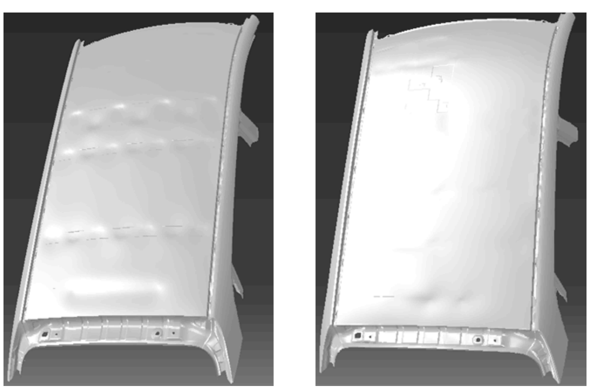


Figure 2: Curvature change o the roof, (left) mastic sealer model, (right)simple beam

3 FLEXURAL FUNCTION

The defective product judgment of the roof is made by polarized light test with a naked eye. This process consumes time and labor because it depends on trial and error process. If curvature change can be predicted in the design stage, it will be more efficient and increase the quality of the product.

The product judged as defective is due to the curvature change of the roof. There is limitation to say that there is a change in curvature just by displacement difference because the change in curvature behaves in three dimensions. So the curvature difference is observed by measuring the difference in slope of the surface before and after the oven process considering the surface mesh.

The normal vector can be found by equation (1) and equation (2) by cross product i and I when the surface in the roof before the oven process is assumed as iab and IAB after the process as shown in Fig.3. The angle formed by two surfaces can be obtained by inner product and it is the angle difference comparing before and after the process. The number of surface that includes a material point is not the one considering material point i. If the tetragonal mesh is used, the number of surface that includes material point i is four as shown in Fig.4. So the number of surface that include material point i is counted and change in the angle for each surfaces are calculated. Then as equation (3), the average value is selected for the angle difference for material points i and defined as micro flexion function.

Normal vector of surface iab $$\vec{n} = \frac{\vec{ia} \times \vec{ib}}{\left|\vec{ia} \times \vec{ib}\right|} \tag{1}$$

Normal vector of surface IAB $$\vec{n'} = \frac{\vec{IA} \times \vec{IB}}{\left|\vec{IA} \times \vec{IB}\right|} \tag{2}$$

$$f(\theta) = \frac{1}{m}\sum_{i=1}^{i=m}\theta_i \tag{3}$$

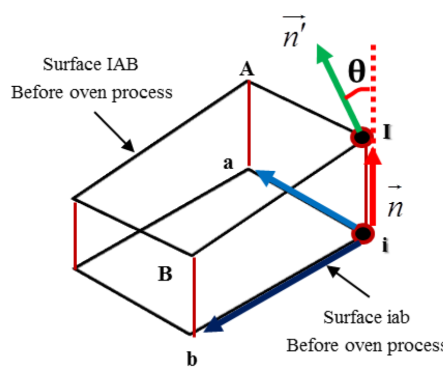


Figure 3: Schematic diagram for definition of deformation flexural function

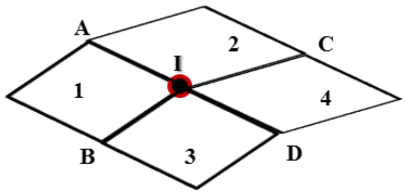


Figure 4: Number of surface including nodel I

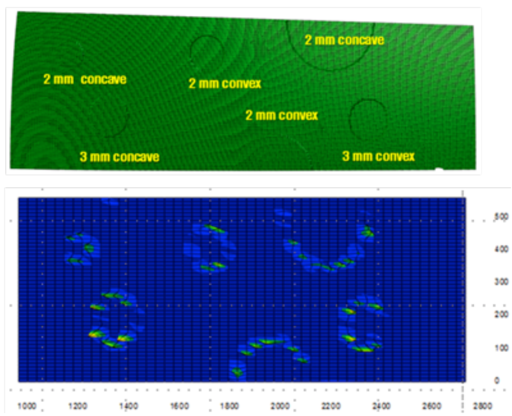


Figure 5: Crater and calculated result

After obtaining the flexural function for each material point, by rendering the value in the direction of xy-plane, the values can be visualized in contour lines. The location with highest flexural function value is where the curvature change will occur by deformation. By comparing the measured curvature function, the judgment can be made whether there is a curvature difference. In order verify the flexural function six craters are purposely made. Then using the flexural function, curvature change is calculated as shown in Fig. 5.

4 MINIMIZATION OF CURVATURE CHANGE

4.1 Sensitivity analysis

Design of experiment(DOE) which was originally introduced to reduce time cost still shows adequate efficiency when the design was proceeded with FEM analysis method [6]. Wang and Hwang confirmed that factor decision and analysis procedure using Taguchi method improved forecasting of various factors [7].

Determined design variables are as follows: arrangement of sealer (S_a), length of each sealer (S_{le}), location of sealer (S_l), end location of sealer (S_e), thickness of roof (R_t), curvature of roof (R_c), thickness of rail (r_t) and location of rail (r_l). To investigate the importance of design variables on deformation of roof, sensitivity analysis of design variables is performed. Sensitivity analysis is a DOE used in Taguchi method. This predicts the most influential factor and relations between factors in relatively fast time for designing of the target process. The flexural function in chapter 3 is used as evaluation criteria for sensitivity analysis. The criticality of factors and sensitivity analysis utilized the result from array $L_{18}(2^1x3^7)$ of Taguchi method.

The result of sensitivity analysis of determined design variables is shown at Table 1. Comparing delta values, more effective factors that affect micro deformation of roof are the location, length of mastic sealer and location of rail. And these main factors are twice more effective than other factors. This means that location and length of mastic sealer located between roof and rail are most effective factors that occurs deformation.

Level	S_a	S_{le}	S_l	S_e
1	0.250	0.252	0.242	0.247
2	0.248	0.253	0.252	0.247
3	-	0.243	0.254	0.255
Delta	0.002	**0.010**	**0.012**	0.008
Level	R_t	R_c	r_t	r_l
1	0.246	0.254	0.251	0.256
2	0.250	0.247	0.251	0.246
3	0.252	0.248	0.246	0.246
Delta	0.005	0.007	0.005	**0.010**

Table 1: Response table result

4.2 Minimization of curvature change on the roof

The results from mean response table of design variables were used to find error function by RSM (Response Surface Method) in specified range. The error function was partially differentiated with numerical method to determine the design variable values that minimize the error [8].

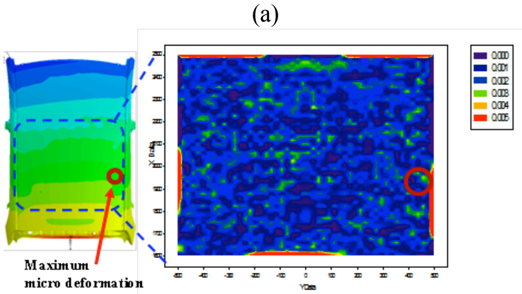
However, application of general minimizes design method is difficult that the range of design variables value is set as constraints. Levels of design variables are limited to different shape type for manufacturing roof to the target design. For this reason, using mean response table for sensitivity analysis, the level that has minimum value of flexural function value is the optimum point. And the optimum point of design variables other than the main variables are set as same way for manufacturing roof without deformation by applying optimum condition of variables. Maximum value and location of deformation are measured after the oven heating process. The maximum value of flexural function is 0.224. Comparing flexural value of before and after optimization, the maximum flexural function value is decreased by 12%.

5 VALIDATION OF THERMAL ANALYSIS METHODOLOGY

To validate the prediction technique of deformation, locations of micro deformation between measurement and computation are compared. Location of deformation of real roof, after oven process, is measured through polarization test. Polarization test is the method to find whether or not the deformation has occurred using long straight fluorescent light. The test model is selected among the current models that are manufactured and same model is analyzed using prediction technique applying thermal analysis as established at chapter 2.

Comparing the location of deformation between measurement and computation, it is confirmed they are same as shown in Fig. 6. Although it is difficult to measure deformation amount through polarization test, by comparing the location of deformation, it is validated that prediction technique of deformation has reliability. Therefore, using prediction technique of deformation established in this research, it is possible to measure quantitatively micro deformation and to minimize deformation efficiently when designing the roof.

(a)



(b)

Figure 6: Location of maximum deformation through (a) polarization test and (b) prediction technique of deformation

6 CONCLUSIONS

In this paper, design process to minimize change in curvature of roof by FE analysis method was established. The validity of the prediction technique is verified by comparing the location of deformation between measurement and computation. Establishing FE analysis method using the flexural function, main design factors to minimize change in curvature of roof during oven process are analyzed. Using main design factors, change in curvature of roof was minimized to optimum value.

(1) To predict deformation accurately, it is essential that forming model of blowing agent such as mastic sealer is determined.
(2) In oven process changing volume of mastic sealer by heating temperature, driving force must be considered.
(3) To measure deformation quantitatively, post process is needed and this process can be done by applying flexural function.
(4) Main design factors to minimize deformation of roof during oven process are location and length of mastic sealer
(5) Comparing experiment and computation, prediction technique of deformation by FEA is validated.

ACKNOWLEGEMENT

This work was supported by the Nuclear Power Core Technology Development Program of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20138540040010)

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