ANALYSIS OF THE PERMANENT DEFORMATION OF AUTOMOBILE HOODS

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ABSTRACT—One factor that determines the quality of an automobile’s appearance is its appearance integrity, which means that the degree to which an automobile’s physical appearance coincides with its mechanical quality. The painting process of an automobile can cause the permanent deformation of its hood, which lowers its appearance integrity. The painting process is comprised of the dipping process and the oven process. In the dipping process, pressure caused by the flow of fluid can cause the deformation of the automobile hood; in the oven process, the thermal deformation of sealers can cause the deformation of the hood. In an effort to increase automobiles’ appearance integrity, this study identifies the major causes of deformation and predicts the types of deformation occurring in each process. The numerical model of a hood is established using the stiffness scanning method and analysis, and deformation in the dipping process is confirmed using Finite Elements Method (FEM). Sealers are hypothesized as the main reason for deformation in the oven process, so a study of the sealers is conducted to predict the deformation occurring after the oven process. Further, through a thermal property experiment and viscosity test, we are able to deduce the properties of sealers that cause deformation. This study also examines the effects of hood deformation in the oven process using numerical analysis and compares the degree of deformation caused by pressure and heat. The results show that the absolute value of deformation in the dipping process is greater than that in the oven process. Moreover, it is shown that deformation can occur bi-directionally in the oven process, and the quantity of mastic sealer does affect the degree of deformation.

KEY WORDS: Automobile hood, Deformation, Dipping process, Oven process, Mastic sealer, Hemming sealer, Foaming model, Curing model

NOMENCLATURE

\( \alpha \): degree of curing
\( H_r \): total heat generation, J/kg
\( A \): area, m\(^2\)
\( \alpha_s \): extent of foaming
\( C_v, l \): material parameters of the driving force model
\( \sigma_p \): pore expansion stress
\( C_p \): specific heat, J/g-°C
\( F_s \): driving force
\( k \): thermal conductivity, W/m-°C
\( \eta \): viscosity, MPa-s
\( \gamma \): rate of heat generation per unit mass
\( \dot{\gamma} \): shear strain rate
\( \tau \): shear stress, MPa
\( \mathbf{n} \): unit normal vector

1. INTRODUCTION

The existing automobile industry places a high value on the performance of cars. Lately, however, design elements such as color and shape have increased in importance.

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in advance is therefore necessary to prevent defects, change design, and promote appearance integrity. It is necessary to examine the characteristics of each process in the design stage to predict and detect how each process affects deformation. It is essential to identify which process contributes most significantly to deformation to reduce design time and costs.

Many studies have been conducted to predict micro-deformation. Deformation in a complicated structure was predicted using a six-step method (Fernlund et al., 2003). It was confirmed that deformation occurred on the roof of automobiles when using Finite Elements Analysis (FEA) through a foaming model, driving force model, and elastic stress model of the sealers applied (Kim et al., 2014). A study on the deformation appearing on an automobile hood during the dipping process by analyzing stiffness was conducted (Kim et al., 2014).

Studies of processes related to temperature must also be considered since deformation can also occur by heat. Deformation by developing a computer simulation model of the heat treatment process was predicted, while simplified formulas to predict the deformation of plate in the steel forming process with induction heating was derived (Lee et al., 2007; Bae et al., 2008).

The volume and properties of sealers change at high temperatures. Because of this, sealers are hypothesized as the main cause of deformation in the oven process. Therefore, a study on the properties of sealers must be conducted to predict deformation in the oven process. As a basis for this, studies of curing behavior have already been conducted; curing model which is called the Kamal and Sourour Model was suggested, and a modified curing model suggested (Rabearison et al., 2009; Zhang et al., 2009). They also deduced thermal conductivity and specific heat depending on temperature and the degree of curing.

There have also been endeavors to simulate curing behavior. Some researchers concentrated on a curing simulation of thermosetting matrix composites with a finite element approach; when materials are cured, an exothermic reaction occurs simultaneously (Yi et al., 1997). Both the heat generation and stress caused by curing polymer were calculated (Heinrich et al., 2012). Further, a study on mastic sealer, including the blowing agent, was performed; a foaming model, driving force model, and elastic model were suggested and verified using FEA (Hwang et al., 2013).

However, existing research has not considered that deformation may change during the successive painting processes. Previous research considered deformation after only dipping process (Kim, 2014). When oven processes are completed, deformation can be increased or decreased. Therefore, this research confirms the deformation occurring in each process to allow for the prediction of deformation through the identification of main contributing factors in each process.

2. THERMAL PROPERTIES OF SEALERS

In the oven heating process, heat is the only external force exerted, so deformation can occur as a result of a change in sealer properties that is caused by heat. Some amount of deformation also happens due to thermal expansion. But the deformation is very rarely the cause of thermal expansion. Because the change in sealer properties occurs in lower temperature than it where thermal expansion of hood materials happens. This paper concentrate in the deformation caused by sealers.

There are two sealers present in the hood: mastic sealer and hemming sealer. The phase, characteristics, and volume of sealers change at high temperatures, indicating that sealers are the cause of deformation. For this reason, obtaining the thermal properties of sealers is very important. To secure sealer reliability, a foundation should be prepared upon which to accurately simulate the behaviors of each sealer.

2.1. Mastic Sealer

The material behavior of mastic sealer was studied (Hwang, 2013). Through thermal tests and simulations using DEFORM 2D, the conductivity and specific heat of mastic sealer were obtained. In addition, while passing through the hot oven process, mastic sealer was shown to expand at the same time as it was curing. Volume expansion in mastic sealer is a phenomenon prompted only by heat, in the absence of other external force. To simulate this phenomenon, a foaming model and driving force model were suggested and will be used in this paper.

2.2. Hemming Sealer

2.2.1. Thermal property experiment

To obtain the thermal properties of hemming sealer, a thermal property experiment was conducted. Hemming sealer is a highly viscous fluid before the oven heating process occurs. A specimen for the experiment was created by injecting 2 ml of hemming sealer into a beaker with a height of 51.89 mm, diameter of 34 mm, and thickness of 1.5 mm to confine volume expansion, as shown in Figure 1. Temperature conditions were set up at three levels: 160 °C, 170 °C, and 180 °C. A thermo-couple was used to measure temperature at the center of the sealer with a time interval of 1 second. Hemming sealer was heated for 30 minutes in the oven to the target temperature, then cooled at room temperature for 30 minutes. Repeating this procedure three times, we obtained a time versus heating and cooling curve. The results of three experiments under each condition almost corresponded, and the average value was used as the experiment value.

As shown in Figure 2, it was confirmed that the curing reaction took place as a result of heat during the high-temperature oven process. This is why there is a thermosetting resin in the hemming sealer. Hemming sealer