Study on the flow behavior of SMC products

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Abstract

SMC possesses the superior features such as high processing ability or good surface smoothness without any particular technique. Therefore it is used for relatively large composite structures such as bath unit.

On the other hand, since SMC is composed of short fiber and large amount of fillers, that leads complex material flow during compression molding process and the large scatter of mechanical properties. As a consequence, the material flow behavior should be understood to design the SMC products. SMC materials are usually set in a die as the laminated materials so that several SMC laminates are stacked together. Material flow of SMC is not uniform such as metal forming. The slippage flows between laminates, which were typical flow behavior of SMC at initial stage in compression molding, have been already found. It is considered that the initial flow behavior greatly affects on following flow and filling process.

In this study, the initial flow behavior characterized by slippage was analyzed with using large deformation finite element analysis. Particularly it is noted here that double nodes were set between layers in order to display slippage flow.

1. Introduction

Compression molding for Sheet Molding Compound have good productivity and good processability. SMC products have good smooth surface and high modulus, therefore SMC has been used in housing, car industries, and so on. Raw SMC is the sheet shaped materials consist of glass fiber mat, unsaturated polyester, and several kinds of fillers. Usually, material flow occurs during compression molding process. It is said that mechanical property of SMC was affected by molding condition[1]. However, regarding to molding techniques of products were made by the engineer or expert, thus flow behavior in the mold is not so clear.

The purpose of this study is establishing CAE system for SMC compression molding. Fig.1 shows proposed flow chart of CAE system, in which curing analysis has been already investigated by the authors[2]. In this paper we focused the initial deformation state. Analysis method was performed by using double node, and elastic- plastic analysis.

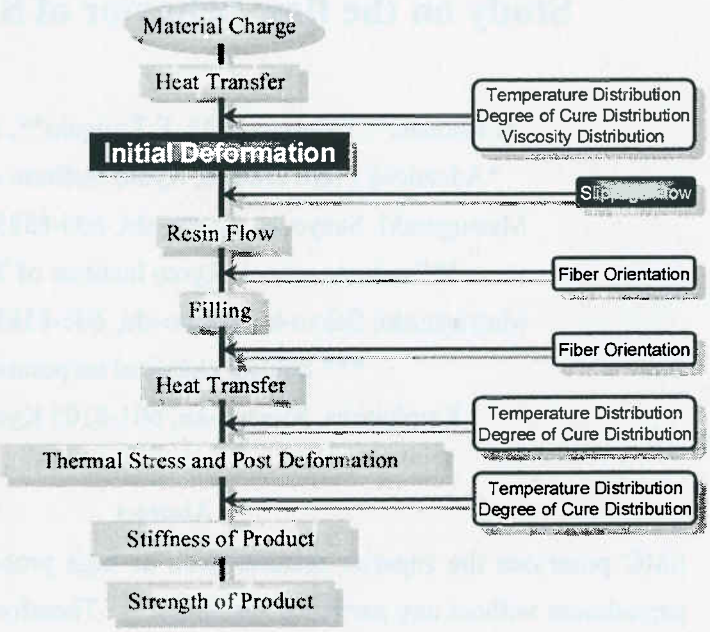
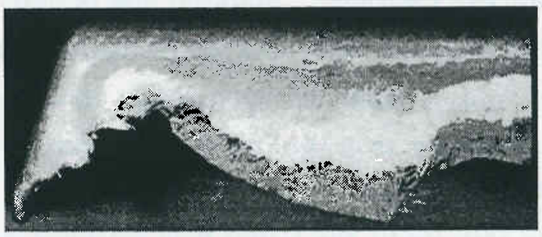


Fig.1 Integrated CAE system for SMC compression molding.

2. Slippage flow

When SMC was molded, normally, several SMC plies were stacked, so that SMC material can be regarded as laminate materials. Because one SMC ply consist of random glass fiber mat layer and resin layer, one SMC ply also can be called laminate material. Therefore, several interfaces exist in SMC layers. In these interfaces, slippage flow occurs during fabrication. Fig.2 shows photographs of short- shot products using flat mold and bath mold. From these photographs, it is clear that slippage flow occurred at interface between each SMC plies. The short- shot product of flat mold have proceed inter- layers, and short- shot product of bath molding have complicated material flow.

a) Flat square product



b) Bath unit product

Fig.2 Slippage flow.

One of reasons for occurring slippage flow is viscosity distribution of materials. When SMC molding is performed, SMC is charged on the lower mold firstly, and then the upper mold touch. This process make time margin. As a result, this time margin cause distribution of material temperature. Before curing, the material's temperature is higher, the material's viscosity is lower.

So that material have distribution of viscosity. Accordingly, material viscosity distribute in the thickness direction, it is considered that slippage flow is caused by interface. For the purpose of describing slippage for SMC, viscosity distribution due to change of temperature is important.

3. Analysis System-1

3-1. Double node and Spring element

Fig.3 shows finite element division. This element mesh was modeled for laminated 3 SMC layers (40mm×40mm×4mm). Large deformation analysis was performed. Von- Mises condition was used for yielding condition. Finite elements used in this study were 8 node solid element. In this study, SMC material is treated as elastic- perfect- plastic material.

Plane HIJ and plane KLM express the interlamina of SMC layers. Double nodes are set on Plane HIJ, plane KLM, plane EFG and plane NOP. The boundary conditions are follows ;

Plane ABCD	:	x-, y-displacements are fixed
		z-displacement is applied –0.1 mm by one step
Plane QRS	:	x-, y-, z-displacements are fixed
Plane ADQ	:	x-, y-displacements are fixed
Plane ABRQ, and CDS	:	x-, y-displacements are fixed

For expressing the slippage flow, spring elements are applied to double nodes connection[3]. Spring constants in x and y direction were 0.1, and that in z- direction was 100. In this paper, it is considered that outmost layers are cured, so that elastic modulus was different in outmost layers and inner layers. The elastic modulus in outmost layer was higher than that in inner layer.

3-2. Result

Fig.4 shows deformed mesh in 25 step. Separation of each double nodes were observed at intra and interlamina of layers, so that slippage flow occurred in intra and interlamina of SMC. And, this

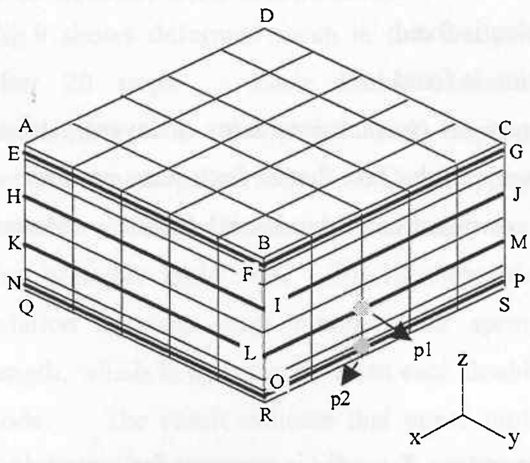


Fig.3 Finite element mesh.

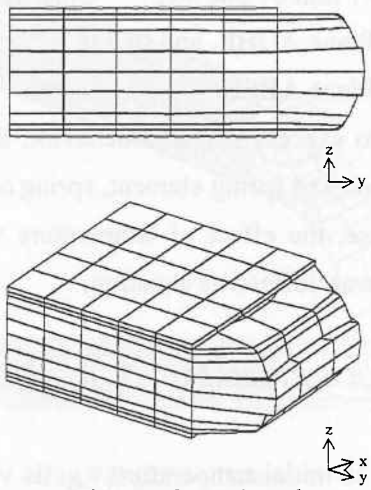


Fig.4 Deformed mesh.

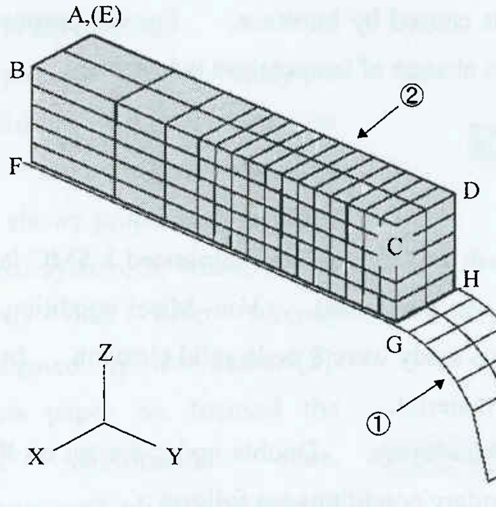


Fig.5 Finite element mesh.

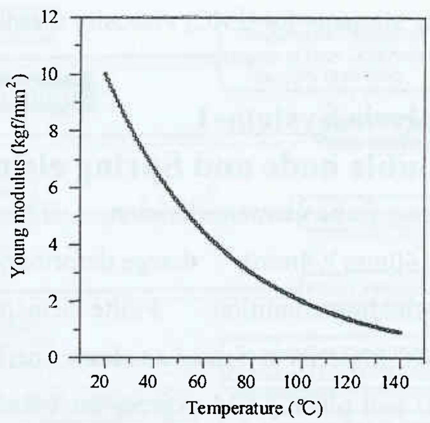


Fig.6 Young modulus-temperature curve.

shape of mesh deformation looked like the real slippage flow obtained by the experiments. The results indicated that using double nodes and spring elements were available to describe the initial slippage deformation.

4. Analysis system-2

4-1. Distribution of Viscosity

From the case of flat square products, it was cleared that using double nodes and spring elements were available to describe the initial slippage deformation. Next, the case of that the products have corner parts were concerned. Fig.5 shows finite element division. Analysis model was initial behavior of 5 SMC layers laminated condition. One SMC layer has 2 mm thickness.

Material condition was same as case of flat square products. In Fig.5, lower mold was defined as wall. Upper mold closing condition was defined as boundary condition which z-direction was applied -0.1 mm by one step. Other boundary conditions are follows,

Plane ADHE, and BCGF : x-direction is fixed

Plane ABFE : y-direction is fixed

In order to express slippage behavior, double nodes were set on each interfaces of layers. Each double node had spring element, spring constants were same as the case that of flat square product.

In this case, the effect of temperature was took into consideration for material factor. Material viscosity was defined as equation,

$$\mu = \mu_0 \exp\{\beta(T - T_0)\} \cdots (1)$$

where, T_0 is initial temperature, μ is viscosity in temperature T. β is constant for material, β is 0.02 in this paper. In this analysis, it was regarded that elastic modulus was equivalent to viscosity. Therefore next equation was used in this analysis,

$$E = E_0 \exp[\beta(T - T_0)] \cdots (2)$$

E_0 is initial elasticity, in the case of temperature T_0. Fig.6 shows relation between elasticity and temperature. For obtaining distribution of temperature, heat conduction analysis was performed. Initial temperature was follows, 140 degree on lower mold, 20 degree on the other parts. Heat conductivity k equal to 1.2×10^{-7}kcal/mm℃s. Material density ρ equals 1.7×10^{-6}kg/mm℃s, specific heat c equals 0.55kcal/kg ℃. Fig.7 shows temperature curve obtained by heat conduction analysis in each layer. It took 30 seconds that the upper die touched the material charged on the lower die; time margin was 30 seconds in this paper. Thus the viscosity used in the analysis was calculated by the temperature as shown in Fig.7 (30 seconds) and the elastic distribution is shown in Fig.8.

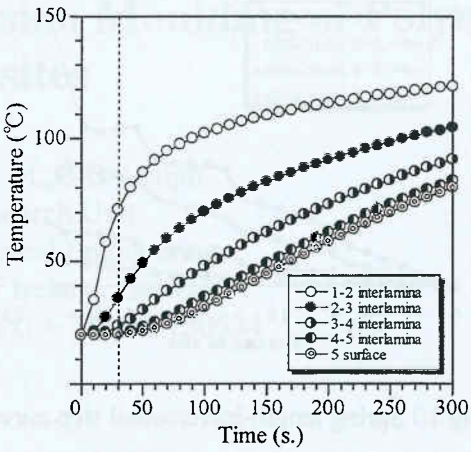
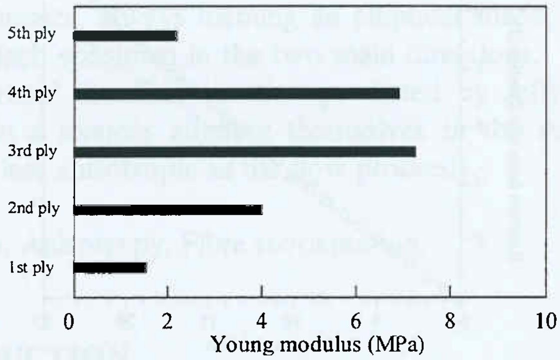


Fig.7 Temperature -time curve.



	1st ply	2nd ply	3rd ply	4th ply	5th ply
Temperature (℃)	112.7	65.4	35.9	38.3	95.2
Young modulus (MPa)	1.57	4.03	7.28	6.93	2.22

Fig.8 Young modulus and temperature of analytical model for SMC product with curved part .

4-2. Result and Discussion

Fig.9 shows deformed mesh in this analysis, after 20 steps. Each double node on interlamina was deformed, and slippage behavior was observed. The slippage behavior of lower mold side was larger than that of upper mold side. Fig.10 shows the relation between step number and spring length, which is distance between each double node. The result indicate that upper mold side have large slippage behavior. It was considered that upper mold side material was

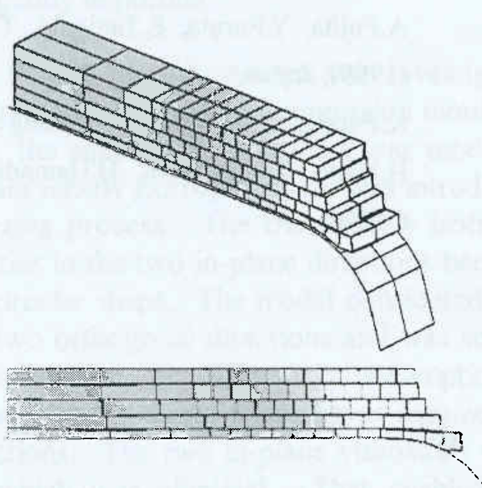


Fig.9 Deformed mesh.

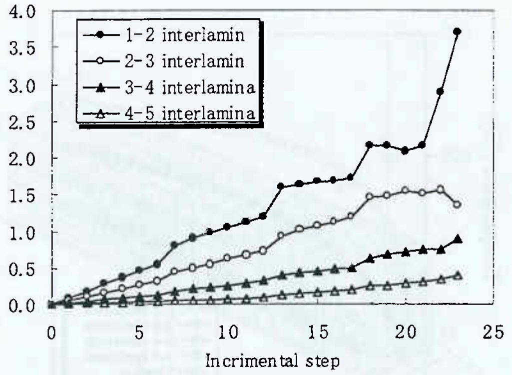


Fig.10 Spring length-incremental step curve.

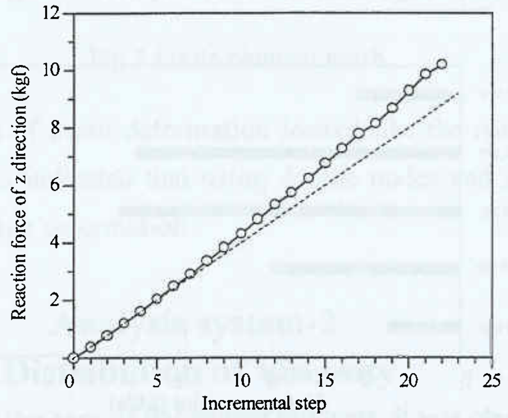


Fig.11 Reaction force-incremental step curve.

easy to deform caused by the effect of thermal diffusion. Fig.11 shows the relation between step number and average of reaction force which z-direction of plane ABCD. The reaction force was regarded as molding pressure during compression molding. Initially, reaction force increased in linear, step number was larger, reaction force increased smaller. The results of this analysis are almost same as the experiment results as shown in Fig.2. It was considered that the analytical model suggested in this study, would be able to express material behavior during SMC compression molding.

5. Conclusion

Analytical model for slippage flow behavior were proposed. In the analysis double node and spring element between the double nodes were used to express the slippage flow. Analytical results had a good agreement with the experimental results.

Reference

1. A.Fujita, Y.Furuta, E.Tanigaki, T.Hasegawa, H.Hamada, *Zairyo* Vol.48, No.3, pp289-294 (1999), *Japan*
2. K.Futamata, H.Naito, *Proceeding of International SAMPE Symposium*, (1997)
3. H.Naito, T.Hasegawa, H.Hamada, *Proceedings of International Composites EXPO '98* (1998)