EXPERIMENTAL AND NUMERICAL FLOW ANALYSIS IN SMC COMPRESSION MOULDING UNDER LOW CHARGE RATIO

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ABSTRACT

SMC is used in manufacture of automobile parts advantages of weightsaving, especially by being applied one-piece panel components with reinforcing ribs. However, the problem of sink marks made at the back surface of the rib must be overcome. Normally in SMC moulding the charge ratio is kept considerable smaller than the full case to improve a sink mark fault. Under the circumstance, the following flow state would be originated at the domain in branching flow configuration being the one of the sequential flow along plain mould part to overcome the flow resistance in contracted canal by the increasing punch stroke and other of filling stream progressing into rib part against distorted traction. It is considered in this paper kinematically admissible velocity field at the above mentioned domain to approach the results of flow state through rib channel.

KEYWORDS: SMC Moulding; Charge Pattern; Fiber/glass; Finite Element Analysis; Sink Mark

1. INTRODUCTION

Sheet moulding compound (SMC) can provide weight reduction and it is seen as being a useful material for attaining compliance with the expected enforcement of tougher CAFE regulation in the U.A. in the future. However, the fact being as composite material of SMC has yet to be resolved. For instance, in the case of large one-piece panels, it is a common practice to use a number of reinforcing ribs to increase panel rigidity.

During the moulding process, sink marks, having a depth of several microns, are apt to occur on the panel surface corresponding to the back of the ribs. In addition, there are also times when the resin and fibre reinforcement are not uniformly distributed, resulting in localized resin-rich areas that causes strength and rigidity to decline. A numerical procedure has been developed by FEM in previous papers[1] for use in analysing the behaviour of SMC during the moulding process. This analytical procedure has been used to examine how various study the authors proposed a sink mark mechanism based on the results of numerical analysis and corroborative experimentation.[2][3] This paper presents the results of analysis and experimentation in which an examination was made of an asymmetrical material pattern in case of charge ratio being kept considerable smaller than the full case to improve a sink mark fault as practical method with experience.

2. RHEOLOGY OF COMPOSITES IN COMPRESSION MOULDING

It is necessary to analyse the in-mould flow behaviour of SMC during unsteady forming process to overcome the faults in practice such as sink marks, weld line and warpage. The unsteady flow state occurring during a press forming process should be analysed using a Lagrangean description, but a simpler analysis will be used employing a progressive step-by-step formulation method using an Eulerian description.[1]

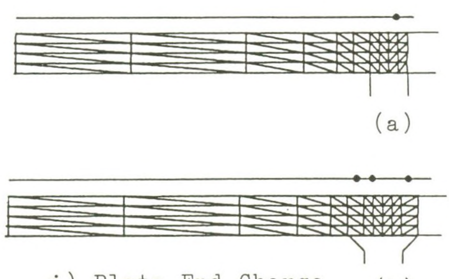
At the first step the deformation state does not depend on the compression rate of the punch, but is governed by the eigen mode of deformation state before initiation of flow.

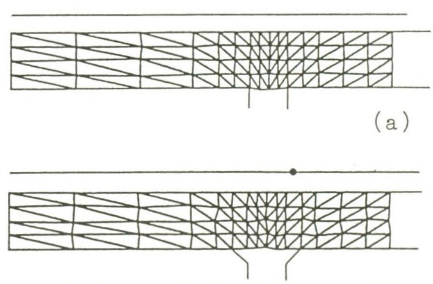
$$[K][\psi]=[M][\psi][\Omega^2] \qquad (1)$$

where $[\psi]=[\psi_j]$ $(j=1,2,...n)$, and $[\Omega^2]=\text{diag.}[\omega_j{}^2]$ and $[K]$ is the stiffness matrix and $[M]$ is the mass matrix. Also $[\Omega^2]$, $[\omega_j]$ and $[\psi]$ are eigenvalue, natural frequency and mode matrix respectively. The first mode should be used to analyse the subsequent process. The practical case of forming a T-shaped component from a flat blank is a typical case and charge patterns of prepreg material are applied to the following three cases, that is, 100% full charge case, the end of material reached at the opposite wall of rib cavity space (Plate End Charge) and end part set over rib channel (Over Rib Charge) as shown in the figures. The sequence of deformation is simulated by linear incremental analysis as shown in Fig.1. The dots show in the figures indicate where the reaction force at the nodal points show stress-free conditions. The phenomenon indicates the possibility of micro-buckling in laminate at the surface. The asymmetry of the dotted nodal point suggests a tendency for any subsequently formed weld line in the rib section. In addition, to investigate the effect of a corner radius on the die, a triangular element is incorporated to form a corner fillet, giving the results shown in each figures in Fig.1(b). The comparison with Fig.1(a) reveals that the sphere of stress free points shows wider, extending to micro-buckling. Since the flow state of a composite material depends on the anisotropic fluid resistance caused by fibre orientation, homogeneous orthotropic pseudo-plastic equations are derived and used as governing equation to analyse the flow state.

$$\rho v_j \frac{\partial v_i}{\partial x_j} + \frac{\partial p}{\partial x_i} - \mu_i(J_2)\nabla^2 v_i = 0 \qquad (2)$$

$$\frac{\partial v_k}{\partial x_k} = 0 \qquad (3)$$





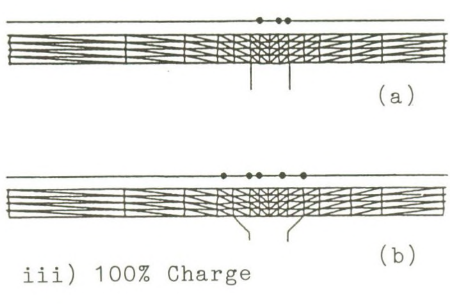


Fig. 1 Mode shape obtained by eigenvalue analysis and release point obtained by linear incremental analysis.

where $\mu_i(J_2)=K_i/3(\sqrt{4J_2/3})^{n-1}$ and $K_i=a_{ij}K_j$ j=L,T. So, the constitutive equations for the orthotropic pseudo-plastic fluid flow can be written,

$$S_{ij} = \mu_i \left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}\right) - p\delta_{ij} \qquad (4)$$

The method of weighted residuals is used to solve the equations. Numerical results for flow states during moulding are obtained as an unsteady flow using the progressive step-by-step method.

3. USING UPPER BOUND APPROACH FOR SMALLER CHARGE RATIO

It might have a tendency to apply a SMC compression moulding to smaller charge ratio of prepreg material in order to improve surface quality overcoming the faults in practice as sink mark. In the case of the asymmetrical pattern, the material flows along the panel surface and so any sink marks that might occur are apt to be filled in. However, this flow pattern along the surface can give rise to selective filling by resin and fibre reinforcement, resulting in nonuniform material distribution that causes rigidity to decline. Therefore, ribs should be designed such that an optimum balance is obtained in the moulding process between surface quality and rigidity as shown in Fig.2. It might be possible to improve a sink mark fault by altering the configuration of smaller charge of SMC. The purpose of this investigation is to develop a design procedure using CAD system to control charge pattern and design configuration of mould with ribs. Then small charge

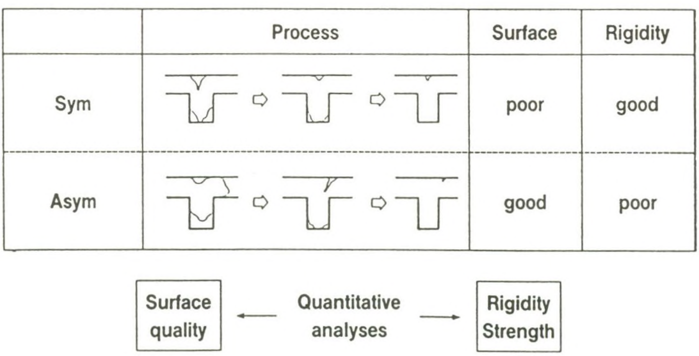


Fig.2 Deference between sym. and asym. flow.

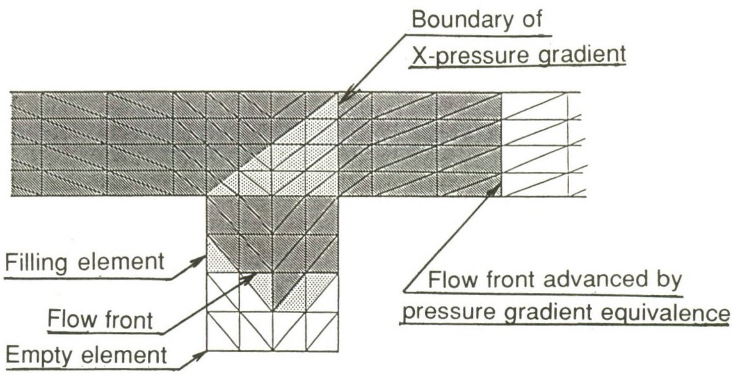


Fig.3 Analytical model at branching flow domain.

ratio is applied in the process, the branching flow ought to set up flowing into sequent plain mould and perpendicular rib channel. It should be considered the kinematically admissible velocity field in the domain, since surface traction by in-mould flow from the plane channel part and distortion into rib part. When the flow front states near the rib part is shown in Fig.3, the solution for flow state could be obtained by upper bound approach. Material flow behaves to hold the equilibrium of flow resistance, considering the behaviour dependent on the incremental deformation caused by progressive punch stroke in the domain, that is, the discriminated domain for the branching flow state shown in the figure. Considering admissible velocity field along the boundary, the following equation is supposed according to hold the equilibrium between the surface traction of inlet to flow front dependent on the resistance into in-mould plane channel and distorted flow to rib cavity part in indicating the viscosity in both direction of plane and orthogonal rib channel shown as x and y.

$$\frac{1}{\mu_x}\frac{\partial p_x}{\partial x} = \frac{1}{\mu_y}\frac{\partial p_y}{\partial y} \qquad (5)$$

where μ_x and μ_y are the coefficient of above directions and $\partial p_x/\partial x$ and $\partial p_y/\partial y$ show the pressure gradient, since the variation of flow resistance might be occurred by the incremental displacement caused by the orientation of reinforcement in both directions. The modelling of the mechanical behaviour during the process is achieved as follows, see Fig.4.

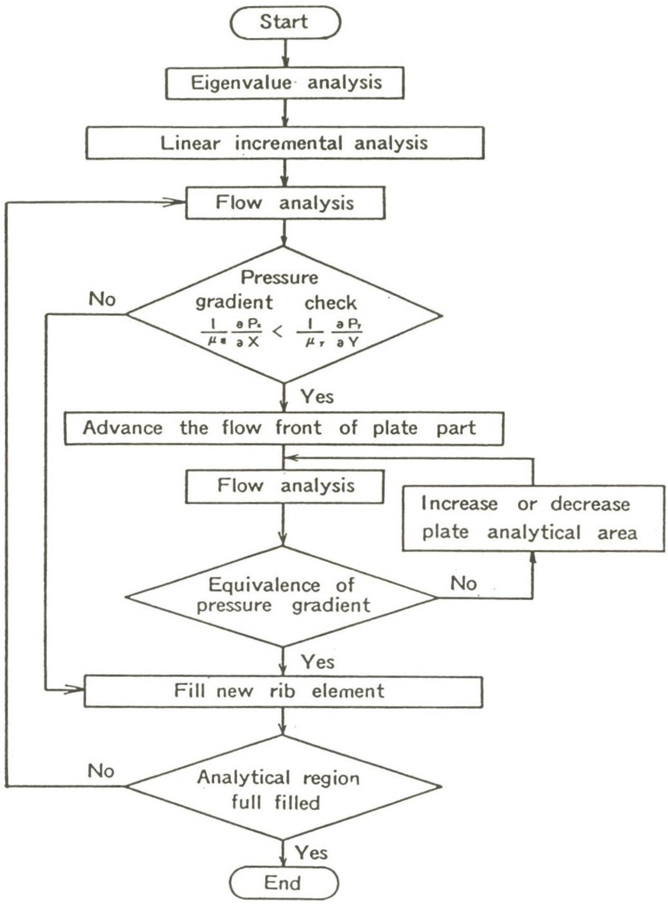


Fig.4 Flow chart of flow analysis regarding the surface traction.

4. ANALYTICAL AND EXPERIMENTAL RESULTS AND DISCUSSION

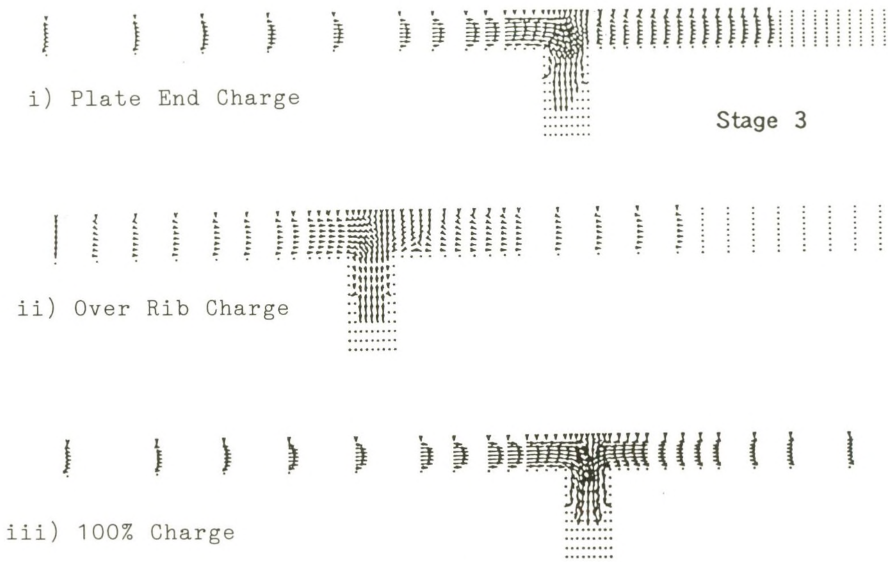
It is also assumed in this paper, the filling behaviour carry out under keeping the equilibrium of surface traction at the boundaries around inlet part of plain and distorted canal depending on out-put from main mould.

The numerical results obtained in the case of Plate End Charge and Over Rib Charge without fillet radius are shown in Fig.5 compared with 100% charge. In the case of Plate End Charge the flow front inclines toward main flow direction in the rib channel. In the case with fillet radius the flow front indicates similar tendency as above but becomes symmetric according to the progressing step. On the contrary in the case of the Over Rib Charge without fillet radius the filling material into rib channel indicates after some progressing flow to plane direction but the filling flow begins to do early from the lower layer of material in the case with fillet radius.

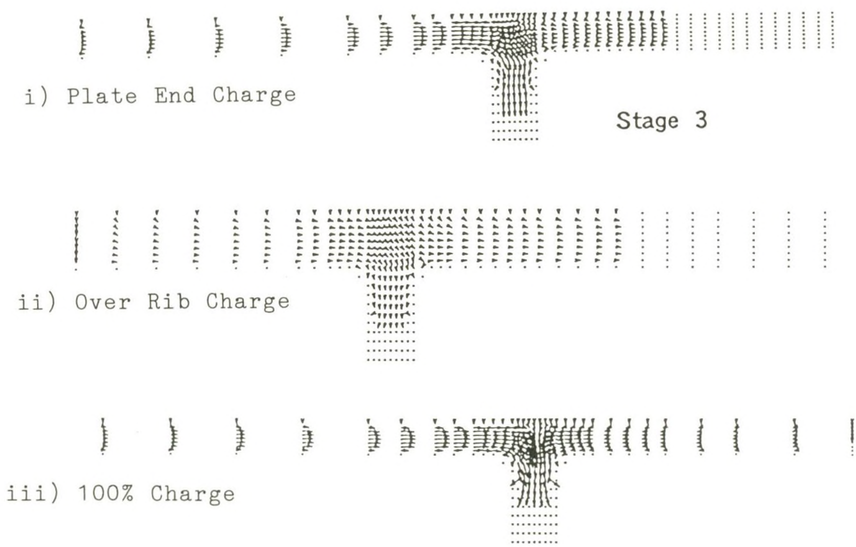
Experimental results in the smaller charge indicate asymmetric filling flow state compared with full charge case either without and with fillet radius as shown in Fig.6 and Fig.7 respectively. In the case of Plate End Charge without fillet radius, though the material flows to plane channel in the beginning step, the filling material flow into rib cavity because of the additional flow resistance caused by the progressive punch stroke. In the case with fillet radius, it might be not originated the sink mark, since the filling moving begins early to do only from the lower layer.

Then a branching flow originates into rib part after the advancing of the process, since it might be smaller resistance against the flat mould caused by becoming narrow dependent on punch stroke than that of distortion filling into rib part at the domain. In the case, the curvature of entrance part of rib have an effect on the flow behaviour, then the branching flow might begin in earlier step. As existence of fillet part suggests a tendency for initiation of weld line as mentioned above in the case of full charge, the problem should be arisen when flow front progresses across through rib part.

The behaviour might give good effect for sink mark formation in order to follow consequence of flow at the behind space in rib part. The tendency for surface sink and weld line are indicated by numerical results shown as in Fig.5 and verified by experimental result in Fig.6 and Fig.7. When flow front passes over the rib part after progress of punch stroke, the resistance in the plane channel direction grows higher and process of filling up into rib is originated earlier. Since the



a) Rib channel without fillet radius (R=0)



b) Rib channel with fillet radius (R≠0)

Fig.5 Velocity vector obtained by flow analysis.

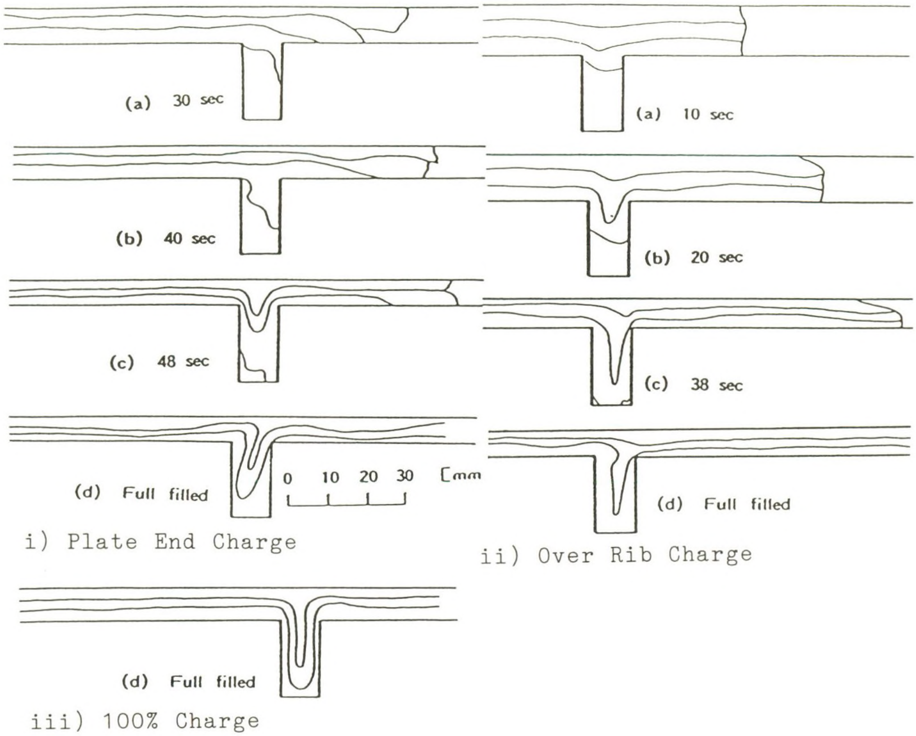


Fig.6 Deformation state obtained by the flow visualization.
(Rib without fillet radius, R=0)

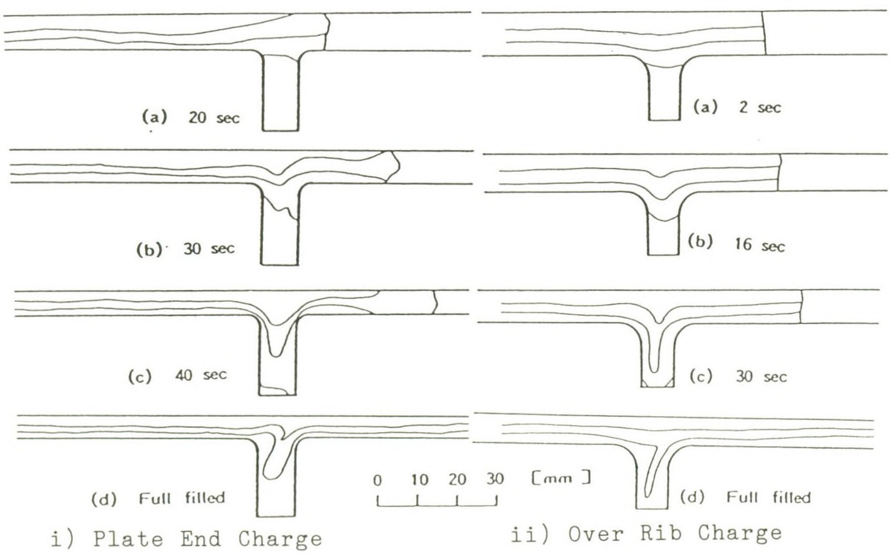


Fig.7 Deformation state obtained by the flow visualization.
(Rib with fillet radius, R≠0)

originated sink mark flows into flat mould constructed as weld line, it might improve a surface quality but weld line is remain in oblique direction. Though surface quality is promoted for smaller charge ratio, the rigidity and strength become very low evaluation caused by asymmetrically mould rib. As the objects are concerned with thicker rib width than practical use for the analysis, it is confirmed the similar behaviour by experiments on practical one.

5. CONCLUSION

The numerical results obtained here by above developed method are shown to be in good agreement with experiment. It might be possible to improve a sink mark and weld line fault by designing the configuration of the mould and the charge pattern of SMC.

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