INTERPRETATION OF CRACK INITIATION IN THE COMPOSITES CAUSED BY THE FLOW STATES DURING PRESS MOULDING PROCESS

Tsuneo HIRAI*, Hiroyuki HAMADA** and Atsushi YOKOYAMA***

* Department of Mechanical Engineering, Doshisha University, Kyoto, Japan

** Osaka Municipal Technical Research Institute, Osaka, Japan

*** Graduate Student of Doshisha University, Kyoto, Japan

(I) INTRODUCTION

Cracks which initiate and progress across the vertical plane section of press moulding products of composites with rib parts appear to be caused by the stress concentration produced at the end surface of weld line[1]. The weak troubles is resulted in the interface formation having no penetrated fibre reinforcements and being moulded by coming together in the part from the both symmetrical opposite surface. To prevent this trouble the mechanism of initiation of the weld line should be made clear.

The aspect of weld line is shown in Fig.1 in the section of the product and the results of the bending test on the specimen with and without weld line is shown in Fig.2. The specimen A is cut out from T-shaped product formed by forward extrusion process and produced the weld line in it. The specimen B has no weld line produced by unidirectional extrusion process. Fig.2 shows the installation of the rib to strengthening the rigidity reduced, rather than added to, the stiffness by the forming of the weld line. And the weld line is resulted in the meander flow shape across the symmetrical axis during the moulding process in Fig.1 in spite of symmetrical shape forming. It is considered that this phenomenon is based on the heterogeneity of composite materials, because the swing phenomenon is not appear in the case of homogeneous isotropic materials. This paper is concerned with the development of the numerical procedure to interpret the phenomenon.

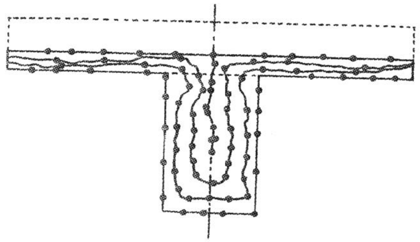

Fig.1 The aspect of weld line.

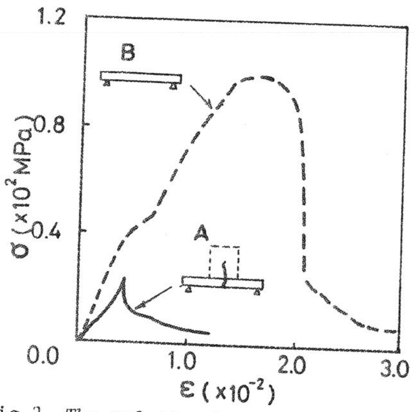

Fig.2 The relation between bending stress and bending strain.

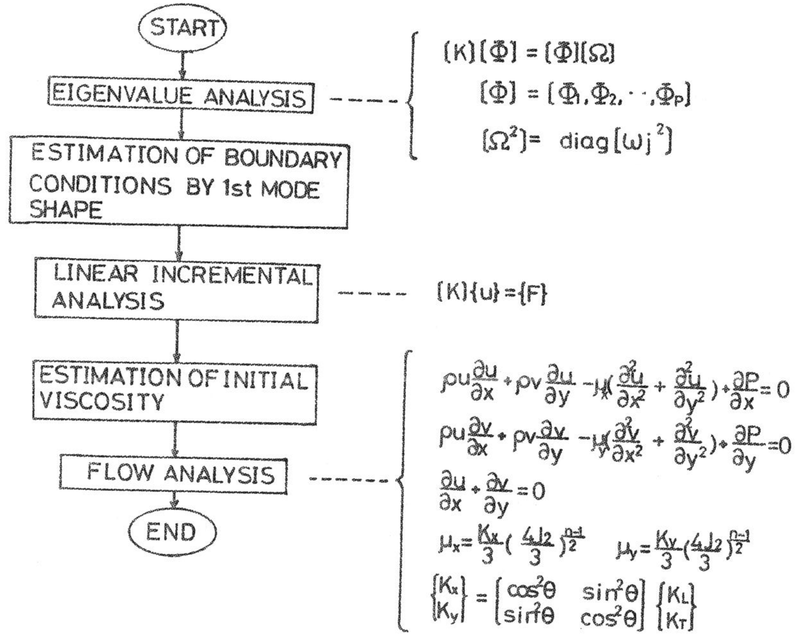

Fig.3 Numerical procedure and basic equations.

(II) NUMERICAL PROCEDURE

The moulding process applying to SMC and BMC is essentially unsteady and should be needed to take consideration on the orientation of reinforcement during the moulding process. This paper shows how well established the modeling can be applied to provide relatively simple methods of analysing and designing the process of orthotropic media.

The numerical procedure developed is shown in Fig.3 as following. At the first step, the material deformation state does not depend on the compression direction of the punch but is governed by the eigen mode of deformation. Then the possibility of deformation before material flow is calculated by eigenvalue analyais[2]. The first mode should be considered to investigate the following process, because the energy level of first mode is lower than the other modes. The result is applied to the second step. The next incremental deformation might be simulated by the linear analysis to the part of infinitesimal deformation. In the step of linear analysis, the displacement along the punch surface is given in the vertical direction but that in horizontal direction is estimated by the first mode of eigenvalue analysis. Lastly under the results of the microscopic analysis, the initial viscosity is estimated and the flow analysis[3)4)] developed by the last paper applied.

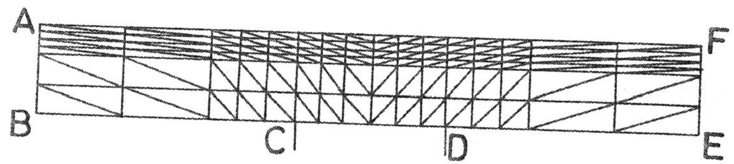

Fig.4 Finite element division.

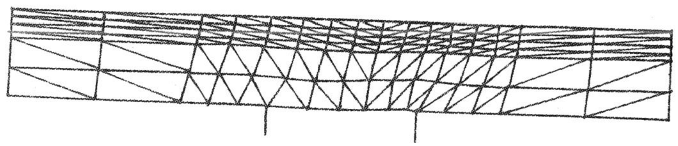

Fig.5 Mode shape obtained by eigenvalue analysis (1st mode).

(III) NUMERICAL RESULTS

As the example of analysing objects the T-type flow canal, that is, the symmetrical shape with rib part is selected to consider an initiation of the weld line. The finite element division of the object is shown in Fig.4, where A-B-C and D-E-F are surface of die, A-F is surface of punch and C-D is a free boundary into rib part. It is considered the composites have the orthogonal anisotropic property depended on the orientation of the reinforcement. The modulus in the horizontal direction is assumed three times in value as much as in the vertical direction, as the reinforcement is oriented to the horizontal direction. Fig.5 shows the first mode obtained by the eigenvalue analysis. This figure shows that the material point shift not only to a vertical direction, but also to a horizontal direction immediately after the loading. This behaviour of deformation causes to rise the swing phenomenon of the weld line.

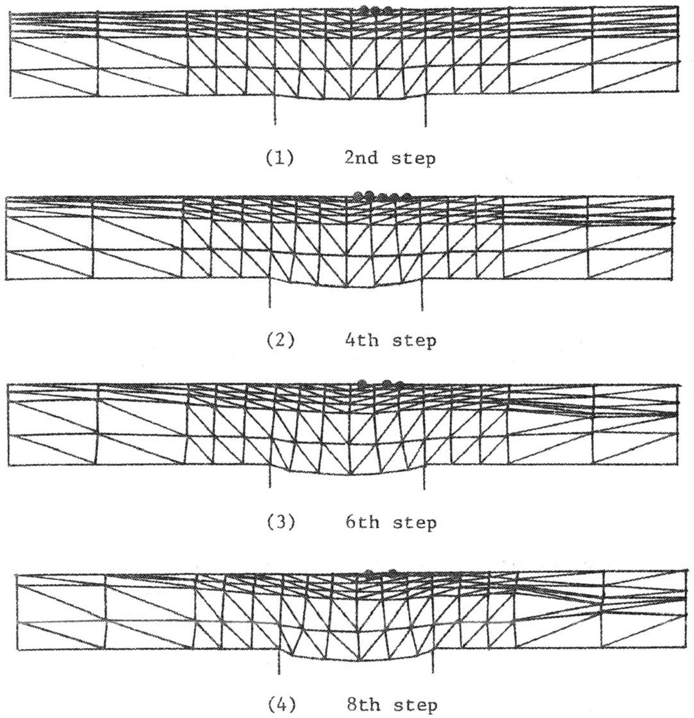

Fig.6 The deformation state obtained by linear incremental analysis to consider the result of eigenvalue analysis.

Nextly the linear incremental deformation theory is done to calculate actual deformation state, where the quantity of displacement is 0.1mm at a time and the increment is repearted 8 times. Furthermore taking the initiation of weld line into consideration, as the reaction force in nodal point on the punch surface shifts from compression to tension, the nodal point transforms freely. Four figures in Fig.6 show the deformation states obtained by the linear incremental analysis on the infinitesimal shift to consider the effect of the eigenvalue analysis obatained above, where $\Delta u=-0.2$ (2nd step), $\Delta u=-0.4$ (4th step), $\Delta u=-0.6$ (6th step) and $\Delta u=-0.8$ (8th step) respectively. The dotted points in the figures show the nodal points under free restriction on the deformation. The states progress, the number of dotted points are increased. Therefore, the numerical results suggest the initiation of weld line and a development of the weld line under the progressive process. The asymmetrical appearance on the dotted nodal points show the tendency to the swing phenomenon of weld line. The progressive numerical results might be clear the tendency of meander flow pattern of weld line considering above results. The procedure estimated the initial viscosity by the linear incremental analysis is shown as following. In the first step, the second order invariant (J2) of strain rate tensor is calculated by the strain rate being obtained by the above calculated strain. As the second, for the purpose of the consideration to the characteristic flow of the composite materials the ratio of pseudo-plastic viscosity Kt/Kl with the directional properties is assumed as 3 indicated an anisotropic flow property. And the deviations of the anisotropic axis are estimated by the gradient of the elemens obtained by the linear analysis shown in Fig.6. Then the initial viscosity for the flow analysis should be able to calculate. Fig.7 shows the distribution of initial velocity vectors in the case of uniform initial viscosity and the flow pattern is symmetry. The distribution of the initial velocity vectors superimposing the effect of initial viscosity obtained by the results of linear incremental analysis is shown in Fig.8. The flow pattern is asymmetry against the axis and might be predicted a tendency of disturbance of flow pattern in the progressive step, because the shape of canal for the material flow is given in symmetry. One example of the numerical results on the flow states during the moulding process is shown in Fig.9 being considered an unsteady flow conditions by the procedure of Progressive Step by Step Method[4] during the process. The flow state shown in Fig.9 resulted in the meander through the corner into the rib, though it is relatively gentle, become of without consideration of the 1st and 2nd step, that is, the starting condition of flow for the calculation. But it was observed that there is the velocity vectors which show the upward flow at the rib part. The above mentioned results show that the numerical method could simulate the characteristic behaviour of composites also asymmetrical flow state in the symmetrical canal.

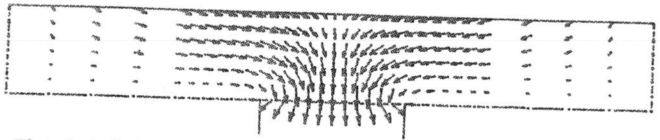

Fig.7 The initial velocity vectors in the case of uniformed initial viscosity.

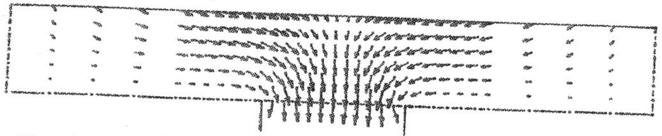

Fig.8 The initial velocity vectors in the case of initial viscosity obtained by the result of linear incremental analysis.

(IV) CONCLUSIONS

Method have been present for analysing the flow state during the press moulding process in which the material flow could be easily imagined as an unsteady. At a standpoint minimizing an energy the eigenvalue and linear incremental analysis are able to applied to predict the progressive flow state at the initial circumstances. The numerical results show the aspect of weld line initiation which cause the fracture damage in the composite strucrure. An additional aspect of this work was to investigate the effective mouhding method to prevent the trouble by applying the lamination of different stiffness.

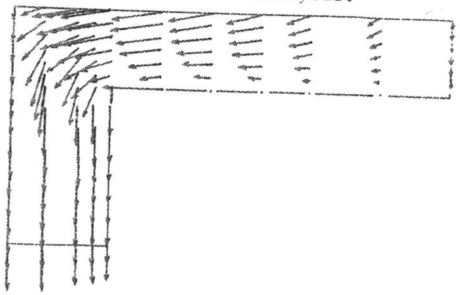

Fig.9 The velocity vectors obtained by Progressive Step by Step Method

ACKNOWLEDGEMENT

This work is supported by Grand-in-Aid for Scientific Research,Japan The authors would like to thank Mr. Hironobu Saka (Graduate Student of Doshisha University) for helpful discussion.

REFERENCE

[1] J.J.Quigley,IV;Proc. of 37th, The Society of Plastic Industry, 14-b(1982)

[2] K.Bathe and E.L.Wilson; Numerical Method in Finite Element Analysis, Prentice-Hall,Inc. (1976)

[3] T.Hirai,T.Katayama;Proc. of the 1978 International Conference on Composite Materials,1233 (1978)

[4] T.Hirai,T.Katayama and H.Hamada; Advances in Composite Materials,1606 (1980)