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Molding Wood-based Composites II
Deformation and Stress Distribution during Mold-pressing

Ping YANG, and Hikaru SASAKI*

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Abstract

In the previous paper[1], the mechanical and dimensional stability properties of moldable wood-based composites were investigated by experiment. The effect of additional adhesive and the PET conjugate fiber content were discussed, and the optimum formulation of moldable composites was ascertained. This is a continuous study focusing on the important quality factors of molded products such as deformation behavior and stress distribution. A numerical analysis using the three-dimensional finite element method (FEM) was developed and carried out to simulate the deformation and stress distribution during mold-pressing. The results may contribute to the prediction of static mechanical properties of molding wood-based composites and to the reasonable design of mold-pressing systems.

Key words: stress distribution, computer simulation, finite element method, moldable wood-based composites, mold-pressing

1. Introduction

Wood-based composite materials are manufactured by bonding wood or other elements together with an adhesive under elevated temperature and pressure. Programs currently used to evaluate the quality of such materials require randomly removing a single full-sized material from a production line, take it into the laboratory, and destructively testing small sections sawn from it. When these tests are completed, the mechanical properties of that particular material could be full known. In order to ensure a proper mold-pressing system could be designed, a quick and accurate nondestructive method of evaluating the mechanical properties of these products is needed. In this study, we try to develop an analytical method to provide some corresponding database for the molding wood-based composites.

As well known, there are many factors effecting on molded products, for instance, complex and irregular geometric shape of dies, complexity in loading patterns, non-linearity and inhomogeneity in properties of moldable materials, etc.. In this study, the simplified and idealized mold-pressing system was selected as an analytical model, and a computation procedure of the deformation behavior and stress distribution in moldable material during mold-pressing with shell dies was established. This analytical method is a three dimensional finite element method (FEM) using 20 nodes hexahedral isoparametric element[2].

All computations were performed on a FACOM 760Q/10 Computer of the Institute for Chemical Research, Kyoto University.

* Wood Research Institute, Kyoto University

2. Analytical method

In view of moldable wood-based composite has a good reformability, especially, deep drawability, a spherical shell was selected as a molded type. Fig. 1 is a schematic diagram showing the simple mold-pressing system containing shell dies and a moldable material before mold-pressing. The radius of curvature and depth of spherical shell die were 130 mm and 10 mm, respectively. The moldable material was a flat circular plate of wood-based composite with 10 mm diameter and 6 mm thick. The analysis was performed on the idealized model shown in Fig. 2. This model consists of 54 elements obtained by means of fictitious cut through a quarter of the flat circular plate because of the axial symmetrical pressing system. Adjoining elements may be thought of as being connected at nodes (total number of nodes is 354), but are elsewhere separated by the imaginary cuts. The elements are 20 nodes hexahedral isoparametric elements. The circle center on the bottom was chosen as the origin of the axis of coordinates.

The analytical model was thought approximately as a homogeneous isotropic material. The

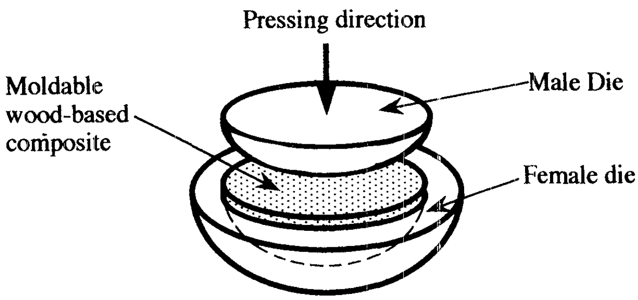

Fig. 1 Schematic diagram of mold-pressing system.

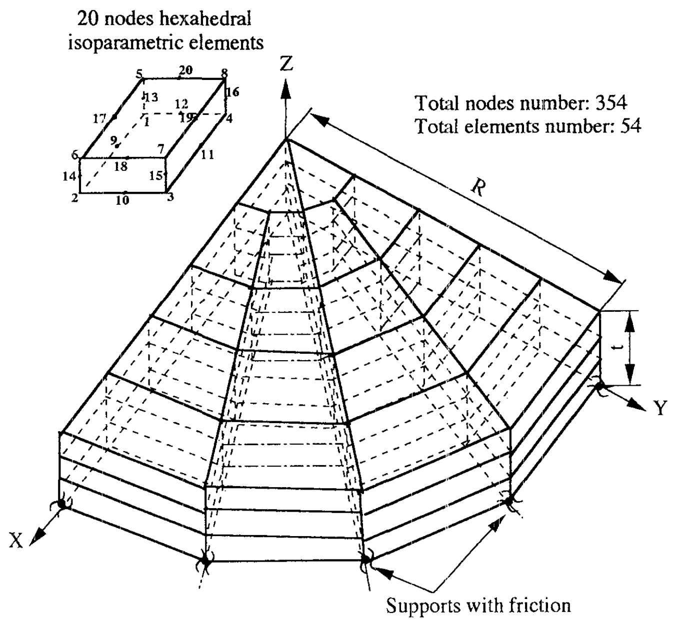

Fig. 2 Analytical model which is divided into 20 nodes hexahedral isoparametric elements.
Nostes : R : Radius, 5 cm ; Thickness, 0.6 cm.

Young's modulus and Poisson's ratio used in the calculation were 1200 kgf/cm^2 and 0.3, respectively. All the nodes on the bottom circular boundary were assumed to be simply supported at the first step. In order to simulate the process of mold-pressing, the distribution of mold-pressure must be determined. This boundary problem could be solved by initially prescribing contact all over the surface and then imposing the load stepwise. For each loading step, the restrained displacements were added to the nodal points on the top surface of moldable material to simulate the distributed load acted from male die. The stress distribution was computed in each iteration cycle and summed up finally.

The incremental displacement during each iteration was set at 1 mm in the downward direction, smaller enough in comparison with board thickness.

Special consideration was given to express the slippage with friction between die and the surface of composite, it was called "the support with friction"[3].

The process of analysis for deformation and stress distribution during mold-pressing is shown in Fig. 3 and described as follows :

At the 1st step, while the male die presses down, restrained displacements were given to the nodes on the top surface of material which contacted with the male die boundary. At the 2nd step, checking the bottom surface if it sinks into female die boundary, if it does, at the 3rd step, reposition of the bottom surface on female die boundary. At the 4th step, comparing the tangential component

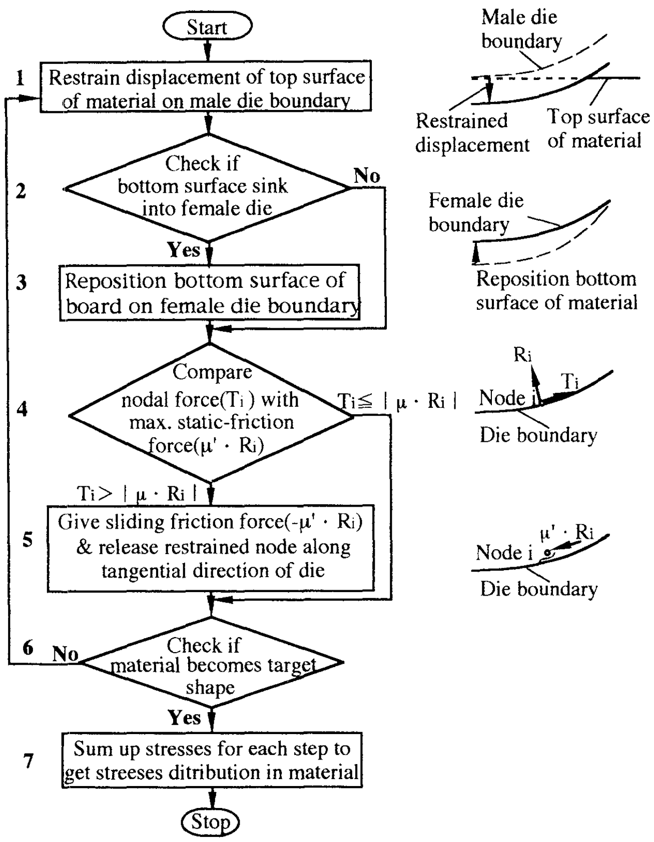

Fig. 3 Process of analysis of deformation and stress distribution in material during mold-pressing.
Note : μ, μ' : Static and sliding friction coefficients between die and material surface
T_i, R_i : Tangential and radial components of the nodal force at the interface

of nodal force (T_i) with maximum static-friction force ($\mu \cdot R_i$, μ : static-friction coefficient, R_i : radial component of nodal force), if the former is larger, going to the 5th step, releasing this restrained node and adding the sliding-friction force ($\mu' \cdot R_i$, μ' : sliding-friction coefficient) as the extra nodal force in the opposite sliding direction (along tangential direction of die). At the 6th step, checking is done if the board becomes shell or not. If a shell is formed, summing up all the components of stress for each step to get the stresses distribution. If not, going back to the 1st step is a must and do the next iteration.

3. Analytical results

Because of axial symmetrical problem, only a cutaway view across the symmetrical z coordinate axis, A-side, was considered. The directions of x, y and z also correspond to the radial, tangential and vertical directions of material boundary, respectively. Fig. 4 shows the deformations of A-side during the process of mold-pressing, a sector of the flat circular plate deforms gradually and finally changes into a spherical shell shape.

The normal stresses σ_x σ_y and σ_z distributing in A-side are shown in Fig. 5. The normal stresses concentrated in the outer circumference of material because of the supplied boundary support conditions. Except in the outer circumference of material, both of the stresses in radial and tangential direction are tensile, and the stresses in vertical direction are compressive because large deformation occurred in material. There is no clear neutral surface in the material, but the much greater tensile stresses occurred on the convex side than that on the concave side. On the circumferential boundary surface, normal stresses changed from tension at the upper to compression at the lower, that may be due to some bending moment caused from given support condition.

Fig. 6 shows the distribution of shear stresses τ_{xy}, τ_{yz} and τ_{zx}. τ_{yz} were much greater than the other two, which may be thought that the critical shear stress occurred on the plane along the longitudinal meridian. The shear stresses concentrated on the lateral circumferential surface too.

4. Conclusion

The method of numerical analysis for deformation behavior and stress distribution in moldable wood-based composites during mold-pressing with shell dies was developed. This analytical method is a three dimensional finite element method using 20 nodes hexahedral isoparametric element.

The features of this analytical method are as follows :

1) An incremental iteration was used with an incremental boundary displacement of die until the composite was mold-pressed to the target shape, because deformation of analytical model was extremely large. After each iteration, the boundary and restrained conditions were determined and the stresses of all nodes were initialized. Finally, the stresses were summed up from all calculation steps.

2) Special consideration was given to express the slippage with friction between die and the surface of composite, it was called "the support with friction". When the tangential component of the nodal force at the interface was greater than the maximum static-friction force, the sliding-friction force was added to the nodal force in the opposite sliding direction, and the node was

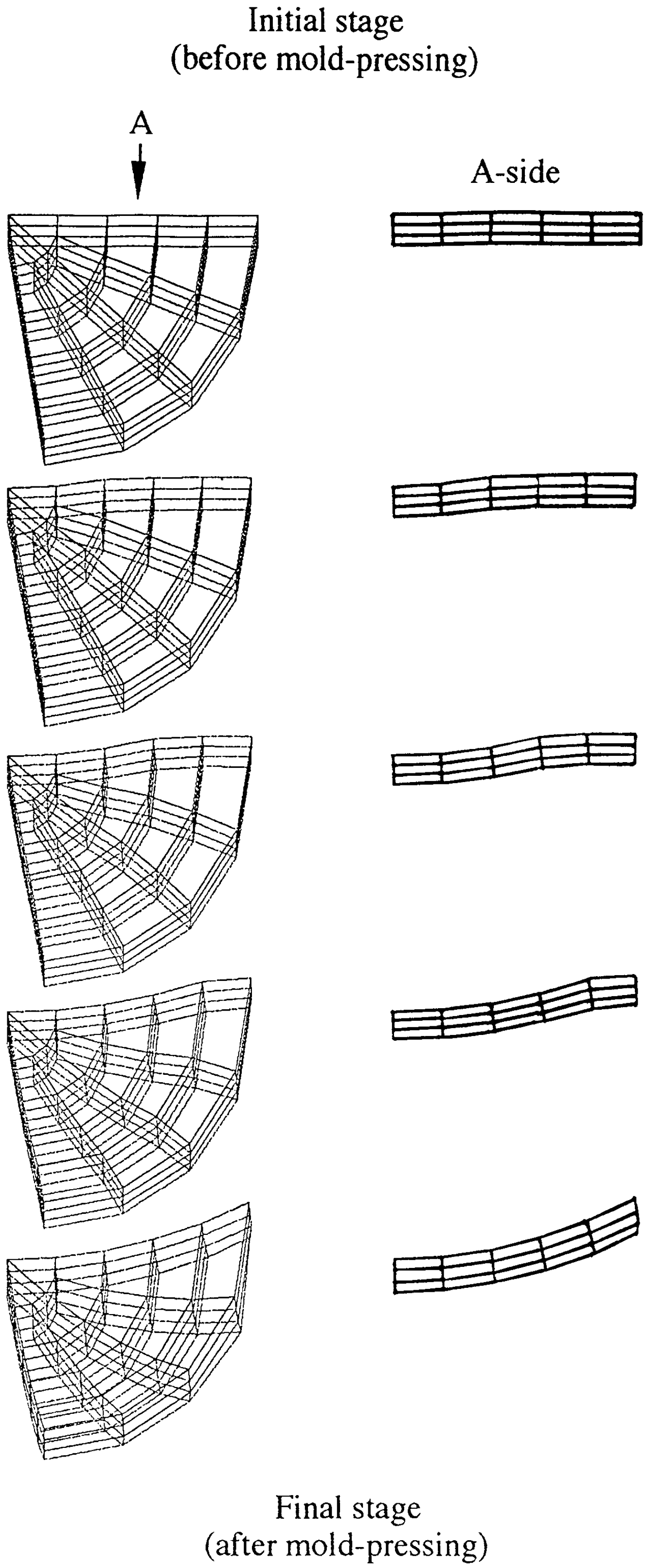

Fig. 4 Deformation of moldable material during mold-pressing.

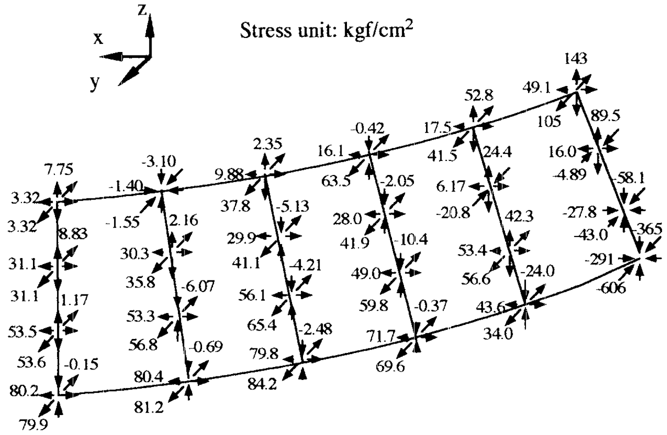

Fig. 5 Normal stresses σ_x, σ_y and σ_z distribution in A-side.

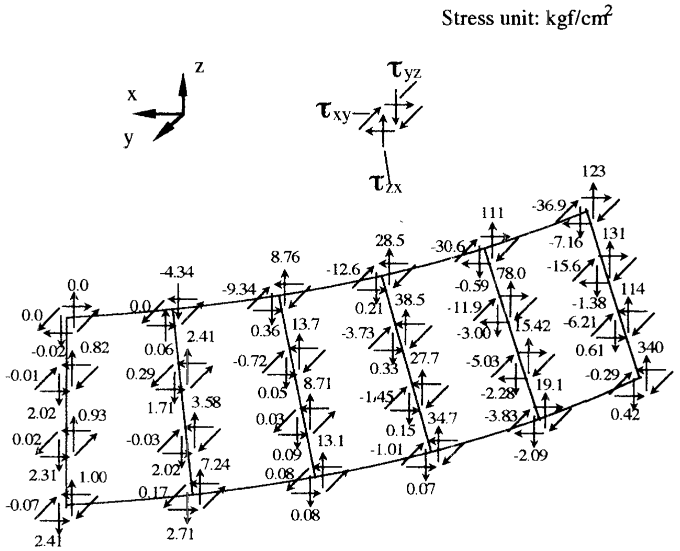

Fig. 6 Shear stersses τ_{xy}, τ_{yz} and τ_{zx} distribution in A-side.

released with a roller in the tangential direction of die. When the tangential component of the nodal force at the interface is smaller than the maximum static-friction force, the node was restrained at that location.

The analytical results showed that all the stress components concentrated on the lateral circumferential surface of the molded product, and the critical shear stress occurred on the plane along the longitudinal meridian.

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