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MODELING DEFORMATION BEHAVIOR OF MOLDED BARK PARTICLEBOARD DURING PRESSING

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SUMMARY: A value-added product of molded sugi (*Cryptomeria* japonica D. Don) bark particleboard was developed for the thermal insulation purpose such as floor underlayment with heating capability. An upper mold with mesh patterns in three-dimensional design was used to produce molded bark particleboards in industrial scale. The thick board with grilled grooves on one side was molded for the plumbing of heating pipes. To acquire a thorough knowledge of the flow behavior of material in the mat during mold-pressing, a numerical analysis using a two-dimensional finite element method (FEM) was conducted. The fundamental material properties of sugi bark particle mat were measured experimentally and used in the analysis. However, the interface behavior between mat and molding tools, including an upper mold and a lower platen, was simulated by contact analysis. However, the mat and tools were treated as deformable and rigid contact bodies, respectively, while the friction between these two bodies is ignored since the tools were covered with fluorine coating for release. Based upon the analytical results, the deformation state of bark particle mat during molding process was clarified. Consequently, the density distribution was found to be in good agreement with that observed from the molded product.

KEYWORDS: Molded Bark Particleboard, Flow Behavior, Analytical Modeling, Computer Simulation, Finite Element Method

INTRODUCTION

Sugi (*Cryptomeria* japonica D. Don) bark has high durability in decay and resisting to fungi. It is also an excellent natural insulation material since its thermal conductivity is much lower than that of sugi timber. However, sugi barks have not been utilized as building material, except as fuel or fertilizer. Recently, a value-added product of molded sugi bark particleboard [1] was developed for the thermal insulation purpose such as floor underlayment (Fig. 1) with heating capability. An upper mold for producing molded bark particleboard was designed to fit a platen of a steam injection hot press. It has mesh patterns with an equal pitch of 150 mm in its horizontal plane so as to produce the thick molded bark particleboards with grilled grooves in 22 mm wide and 9 mm deep on one side for the plumbing of heating pipes. The primary objective of this study is to clarify the flow behavior of material in mat during mold-pressing by the numerical approach using computer simulation, so as to obtain a thorough understanding of formation process of molded bark particleboard. However, the stiffness characteristics of mat used in calculation were determined based upon the stress-strain curve of uniaxial compressive test of sugi bark particle mat during hot pressing.

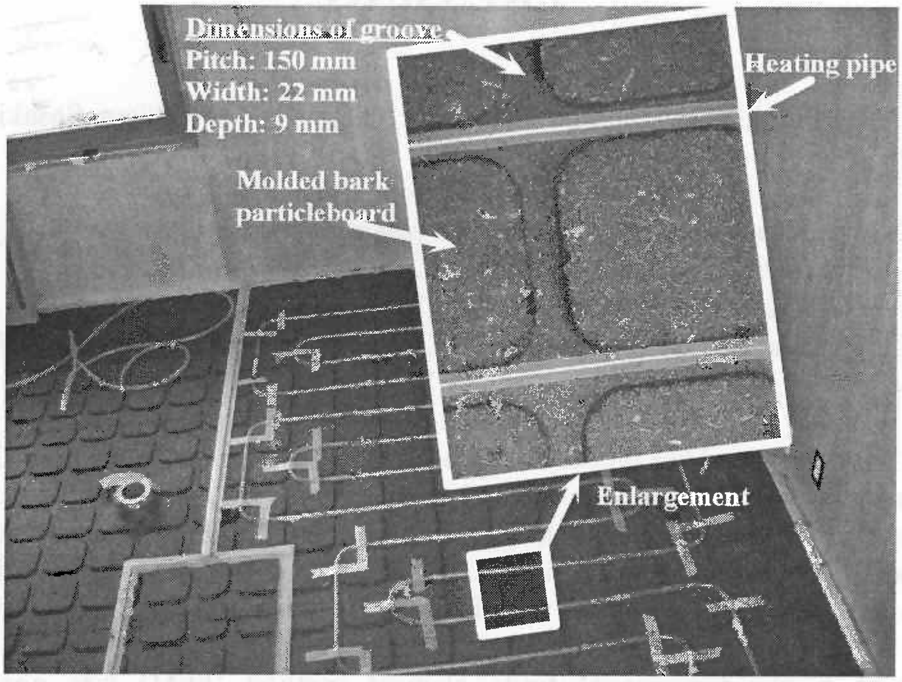

Fig.1 An application of molded bark particleboard in underlayment of heated floor

ANALYTICAL METHOD

Analytical Model

A sugi bark particle mat described as a rectangular patch in 150 mm long and 55 mm thick is pressed vertically by an upper metal mold. The mat in thickness section is assumed to be in state of plane strain. Because of the symmetry in geometry of pressing system, only a right half of one unit molded bark particle mat was taken as an analytical model. Fig. 2 shows the placement of the mat and molding tools including an upper metal mold and a lower hot platen. The upper mold is described as a horizontal line with a groove in the middle, while the groove is composed of two fillets of radius in 2 mm that bring them tangent to the vertical edges of the groove in 22 mm wide and 9 mm deep. However, the lower platen is only expressed as a horizontal straight line. Actually, the initial thickness of mat is 200 mm, and the final target thickness of molded board is 45 mm. Taking into the consideration of that the extreme lower initial stiffness of mat due to its great porous would cause the severely deformed configuration at an intermediate stage, and lead to a premature termination of the analysis due to excessive distortion in the elements, the 200 mm thick initial mat was replaced by a 55 mm thick flat mat with the even initial vertical compressive stress and strain in the analytical model at the first stage for a successful completion of the analysis. This setting reason will be explained hereafter in the section of "Material Properties" of this chapter.

A two-dimensional finite element method (FEM) with four-node elements in the plane strain state was used. The mat was divided into 1320 elements with a total of 1403 nodes. All the elements of mat are uniform in size of 1.25 mm long and 2.5 mm high.

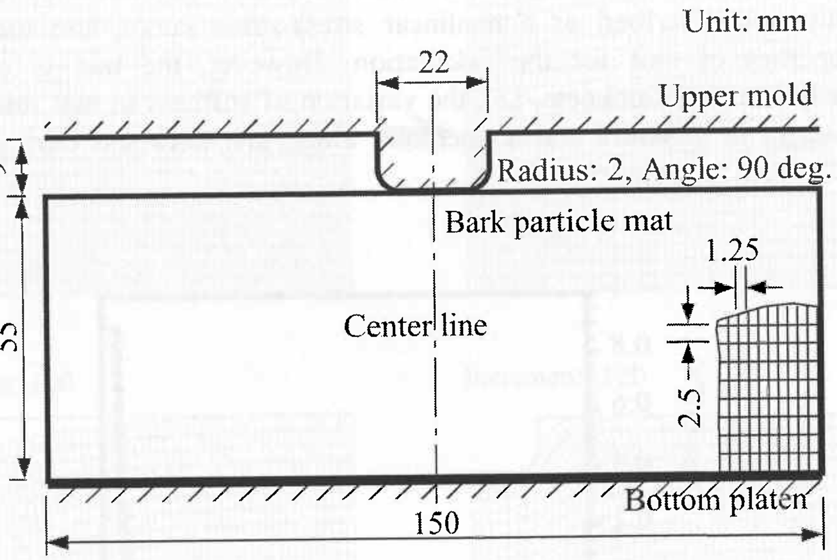

Fig. 2 The analytical model of bark particle mat in mold-pressing system
Notes: Total elements: 1320, Total nodes: 1403

Boundary Conditions

The nodes along the centre line and right edge of mat are clamped to restrain their horizontal translation but free in vertical motion so as to assure the boundary condition where each unit of molded board is independent and symmetric in geometry during mold-pressing.

However, the mold-pressing procedure was treated as to move the upper mold down 19 mm totally towards the static lower platen within 300 equal increments. The molding tools such as the upper mold and the lower platen are considered to be rigid, while the mat is treated as a deformable body during the analysis. The interface behavior between tools and mat was simulated incrementally by contact analysis, while the friction between these two bodies is assumed to be negligible, since the tools were covered with fluorine coating for release. Finally, the molded board would be 45 mm thick in the embossed portion with an average density of 0.4 g/cm^3, and 36 mm thick in the compressed portion of groove with an average density around 0.45 g/cm^3.

Material Properties

The mat was assumed to be continuous, homogeneous and in the state of plane strain. In order to clarify the material behaviour during pressing, a uniaxial compressive test of sugi bark particle mat in hot pressing was conducted. A 200 mm thick and 150 mm square mat was set into two upper and lower aluminium hot platens to be heated to 160 °C, then pressed to 45 mm thick by using a load cell in an Instron universal testing machine. Fig. 3 shows a single stress strain diagram plotted by 39 data points measured from the hot pressing of bark particle mat. It is obviously that the stiffness of mat depends on the compressive ratio of mat significantly. A steep slope was found when the compressive ratio of mat is greater than

0.725. That is the reason why to set a 55 mm thick flat mat (where the compressive ratio of mat is 0.725) with the even initial compressive stress and strain instead of 200 mm thick mat at the first stage in molding process so as to avoid a premature termination of the analysis due to excessive distortion in the elements. The stiffness characteristics of mat obtained experimentally was described as a nonlinear stress-strain curve, and used to define the material properties of mat for the calculation. However, the mat is considered to be homogeneously along its thickness, i.e., the variation of stiffness in mat thickness is ignored since the gradient in moisture and temperature along mat thickness during steam injection pressing is too slight to result in different stiffness.

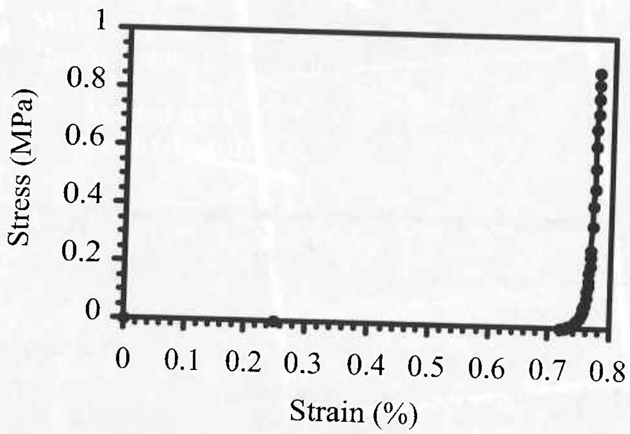

Fig. 3 Stress-strain curve of bark particle mat during hot pressing

MARC Program (Version 2000) developed by MSC. Software Corp. was used. All the computations were performed by using a personal computer with Pentium III-1GHz CPU, and 60 GB-7200 rpm hard disk driver. It takes 408 seconds for one calculation of molding process.

RESULTS AND DISCUSSION

Deformation Behavior of Bark Particle Mat during Molding Process

Several deformation responses of sugi bark particle mat during mold-pressing based on the computer simulation are selected to show in Fig. 4. It could be seen that the contact region between the upper mold and mat extends gradually from the grooved portion to the entire surface of mat. The final deformed configuration of mat shows that the two 90 degrees sharp corners of groove were well developed, while the elements around the reentrant corner become distorted significantly. The phenomenon of material flow in mat during mold-pressing could be also recognized visually from Fig. 4. The result of an irregular density distributed around the groove was obtained quantitatively, which the fluctuation is between -0.3% and +2.8% of the average density. However, the lowest density was found at the tip corner of the groove, which agrees with the observation on the molded bark particleboard.

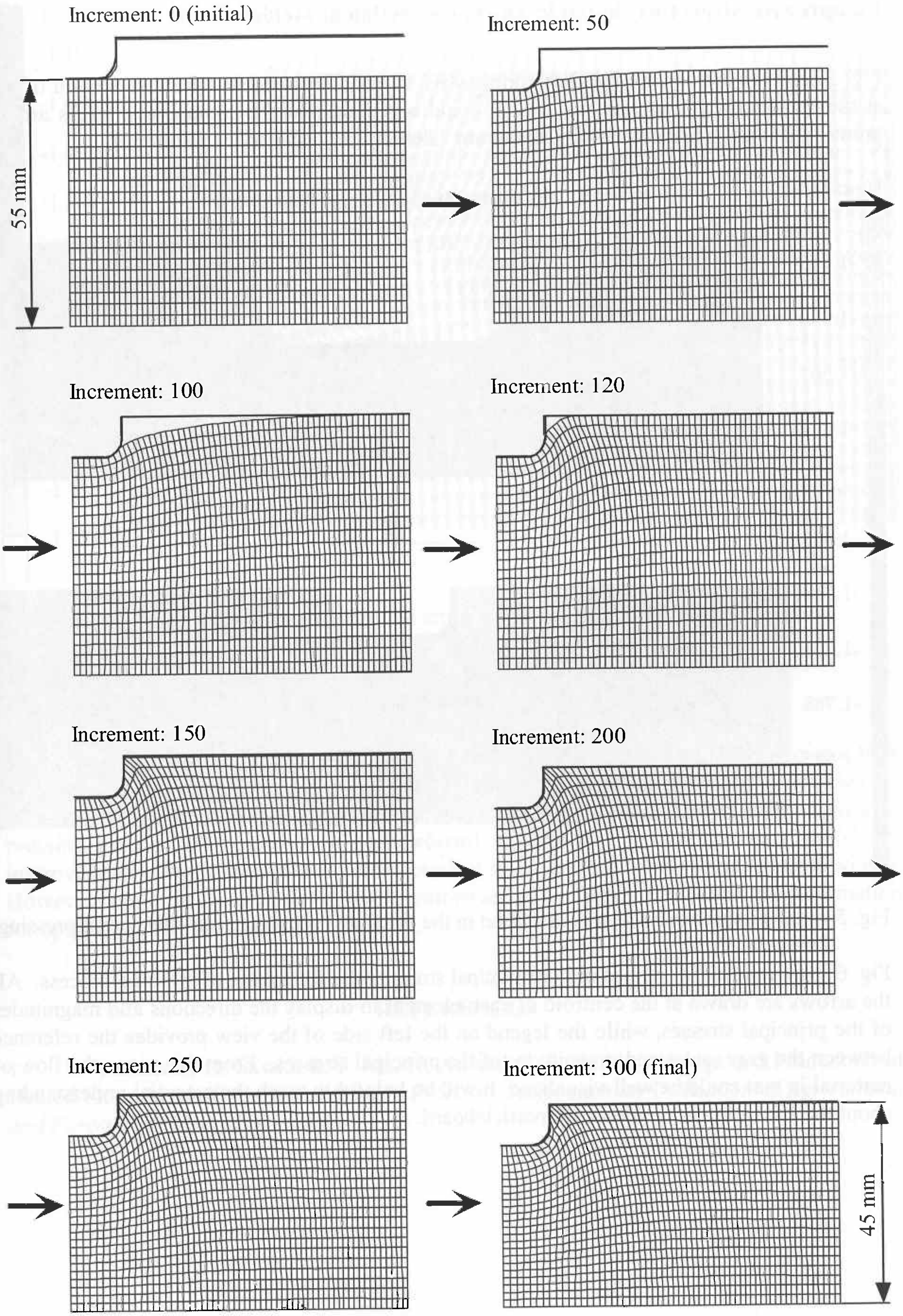

Fig. 4 Deformation of bark particle mat during mold-pressing

Compressive Stress Distributed in Thickness Section of Molded Board

Fig. 5 displays the contour band of compressive stress distributed in thickness section of mat at the final stage in molding process. It could be found that the compressive stress around groove fluctuates significantly. Its maximum value is 1.23 times of the minimum.

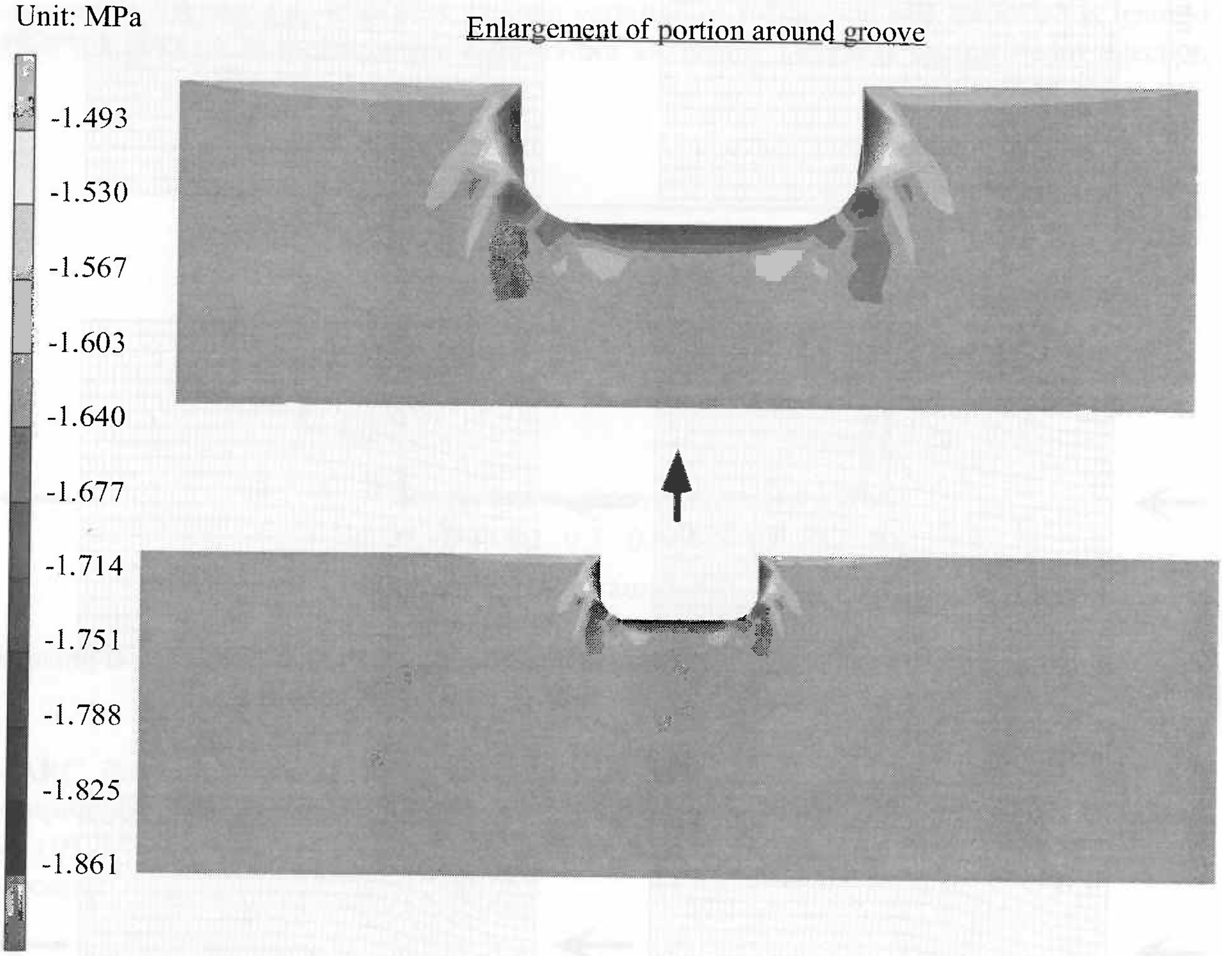

Fig. 5 Final compressive stress distribution in the thickness section of mat during hot pressing

Fig. 6 shows the tensor plot of major principal stress at the final stage of molding process. All the arrows are drawn at the centroid of each element to display the directions and magnitudes of the principal stresses, while the legend on the left side of the view provides the reference between the gray scales and magnitudes of the principal stresses. From this view, the flow of material in mat could be well visualized. It will be helpful to reach the essential understanding about the formation of molded bark particleboard.

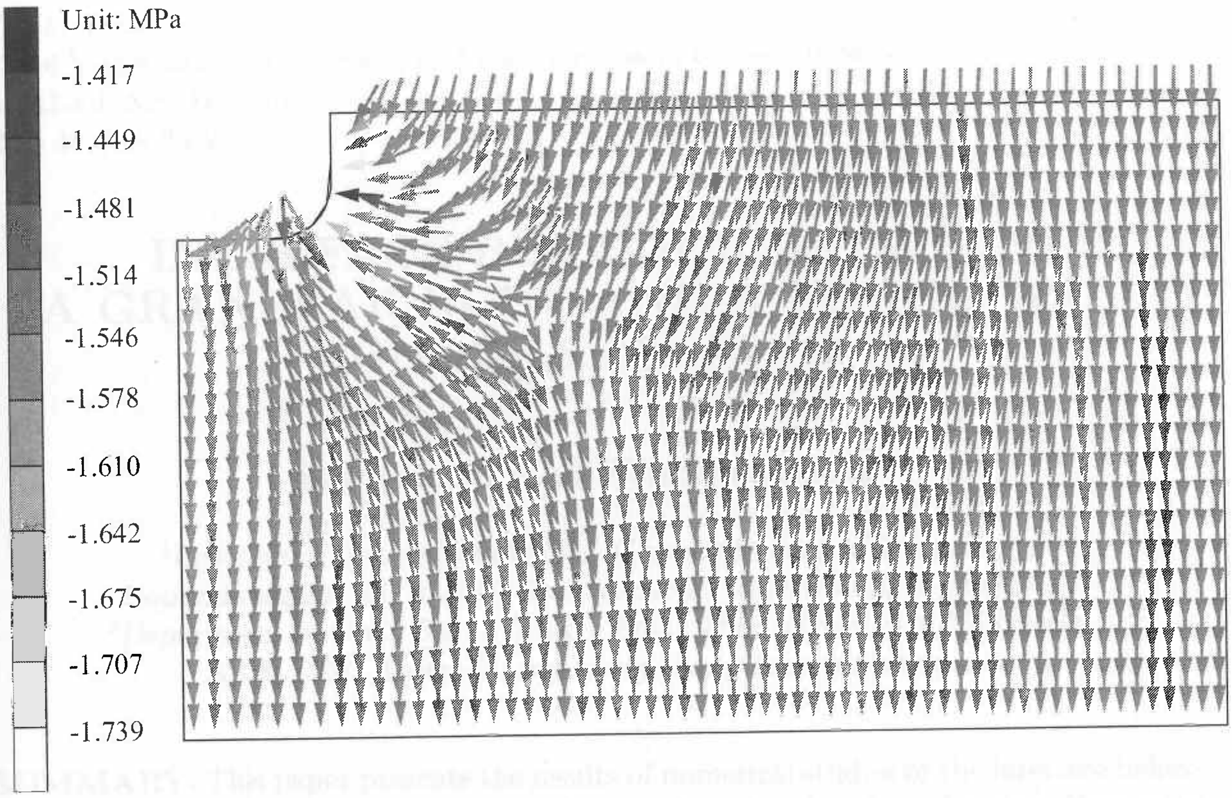

Fig. 6 Tensor plot of major principal stress in the final stage of molding pressing

CONCLUSIONS

This study deals with the deformation behavior and stress distribution in molded bark particleboard during steam injection pressing by computer simulation using the finite element method. Based upon the analytical results, a rudimentary knowledge of material flow in pressing process of molded bark particleboard is obtained. It will be very useful for improving the performance of the molded product so as to extend its application more widely. However, the further experimental investigations are still scheduled to collect the information for optimizing the mold-pressing operation.

REFERENCES

1. H. Yamauchi, H. Sasaki, L. F. Ma, H. Xu and O. R. Pulido, "Design and Production of Heated Floor Panels from Wood Barks", *Proc. of Symposium on Utilization of Agricultural and Forestry Residues*, 2001, pp80.