Strain distribution in wood during chipping

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ABSTRACT

To be able to understand more in detail what actually happens during chipping, the strain field in a chip during chipping was studied by means of the Digital Speckle Photography (DSP) technique. In addition to recording the strain field, the load on and displacement of the chipping tool was also recorded. The equipment used in this study was a DSP system, an MTS servo hydraulic testing machine and a specially developed chipping device. Displacement controlled testing was performed with a crosshead speed of 1.0 mm/s. The results are promising but needs some improvement regarding resolution of the digital images in a vicinity of the knife-edge. The cutting speed in this investigation is low in comparison to normal industrial cutting speeds and since wood in general exhibits a viscoelastic material behaviour this might give a slightly different strain field as compared to an industrial chipping process. However, it is believed that using DSP as a tool for studying the deformations during chipping, even under quite restricted conditions, will increase the understanding of the chipping process. The present study is a part of a larger project aimed at a better understanding of the chip formation and wear mechanisms of wood chipping knifes.

INTRODUCTION

One requirement from the pulp and paper industries is that the chip size (thickness) distribution should be as narrow as possible because it affects for example the packing degree in the compression screws used to transport the chips. It is generally accepted that the chip quality affects the whole pulp production and thereby the properties of the pulp. The ideal chips have a high bulk density and a narrow size distribution. To improve chip quality with regard to chip dimensions and fibre damage, the mechanics of chip formation must be better understood. The purpose of this paper is to present a method, based on digital speckle photography (DSP), for investigating the deformation fields in wood during chipping.

There is experimental evidence indicating that when varying the length of the wood chips in the chipping process (keeping all other parameter constant), the ratio of length to thickness for the chips will be constant in some average sense [1,2]. Depending on what type of chipper that is used and the wood quality, one will have a range of chip lengths and thicknesses, which may be more or less narrow. Variation in the properties of the wood gives a natural variability of 20% [3-5].

When the chipper knife starts to penetrate the log, compression stresses develops parallel to the wood fibres. This compression stress, and the wood's resistance to splitting into individual chips, determines the chip thickness to chip length ratio produced, as well as pin chips and fines generation [6].

In the present study, the strain fields of crack propagation were measured in order to improve the understanding of crack growth in wood and to see if digital speckle photography (DSP) is suitable for this investigation. The system used for the deformation analysis is based on image analysis of the undeformed and deformed images of the wood specimen from which chips are cut. By numerical differentiation of the displacement field, the strain field can be determined. DSP has found great applicability in a number of interesting applications. Thuvander *et* al. [7] used it to study crack tip strain field in wood at the scale of annual growth rings, Jernkvist and Thuvander [8] studied stiffness variation across annual growth rings in Picea abies, Ljungdahl *et* al. [9] studied transverse anisotropy of compressive failure in european oak and Dumail *et* al. [10] analysed rolling shear of spruce wood.

By using DSP it is possible to evaluate quantitatively the in-plane displacement and strain fields. By eliminating the rigid body movement of the specimen, the local deformations on the specimen surface can be determined. Of interest is the local deformation (strain), up to the instant when a chip is formed. Depending on the size of the selected test area, smaller cracks will be captured and visualized as local strain concentrations during the evaluation as well.

The cutting speed in this investigation is low in comparison to normal industrial cutting. The cutting speed has a significant effect on pin chip production as it has on the production of over thick chips [4,11]. Low chipping speed almost certainly results in a high sliding frictional component of the work of chipping [12]. There are other parameters which affects the material behaviour such as temperature, moisture content etc., which have not been considered in this preliminary investigation. In this first study, some preliminary test values are presented.

EQUIPMENT

The ARAMIS measuring system [13] was used for the deformation analysis of the specimen surface for determining the fracture behaviour including the crack development. A hydraulic testing machine (MTS) was used to load the chipping tool. To fix the wood sample, a specimen holder (figure 1) was used. The specimen holder admitted a variation of the cutting angles in both a horizontal and a vertical plane. The whole chipping device is shown in figure 2.

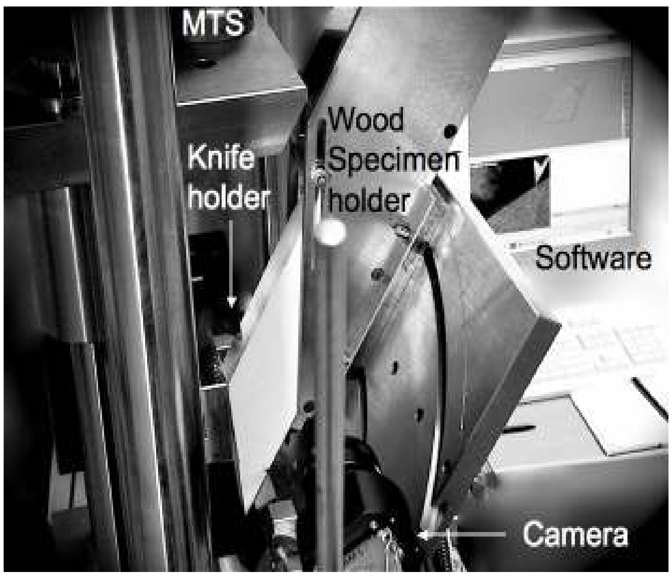

Figure 1. The experimental setup.

Figure 2. The chipping device.

The following cutting angles were chosen: sharpness angle β = 34°, clearance angle α = 3°, spout angle ε = 30° (figure 3).

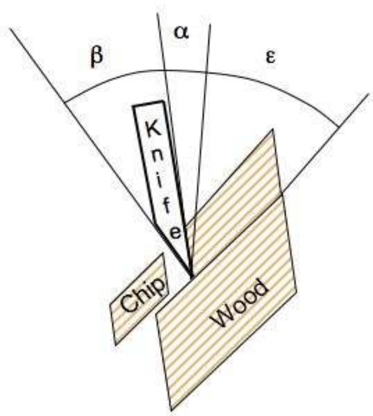

Figure 3. The cutting angles α, β and ε.

The material used in the chipping test was Norwegian spruce (Picea abies). For the test, a specimen with cross section dimensions of 35 x 80 mm^2 was cut and planed. The servo hydraulic testing machine (MTS) was used to load the chipping tool, and a 50 kN load cell was used to measure the applied force. Displacement-controlled testing was performed with a crosshead speed of 1.0 mm/s. A charge-coupled-device (CCD) camera (2D analysis) focused on the part of the specimen closest to the knife-edge and the software was programmed to take 12 photographs per second.

DIGITAL SPECKLE PHOTOGRAPHY

The X and Y displacements are determined from the comparison of two digital images of the specimen surface. One image is taken before loading and the other is taken after loading the specimen. Provided that the surface has a clear and random pattern, corresponding sub regions in the two images can be identified with a pattern recognition algorithm, and the relative displacement of the sub regions can be calculated.

A camera was placed facing a side of the specimen. In order to provide a suitable characteristic pattern for the analysis, the side of the specimen was painted with white paint and thereafter sprayed with black paint. The technique relies on that the motion of this pattern can be detected between frames; therefore the quality of the pattern is crucial.

Once at least two images of the test surface are captured, the relative displacement between them can be calculated. The software included in the equipment calculates the displacement field and the strain field by numerical differentiation of the displacement field. For best results, the sample has to be perpendicular to the camera, and for high resolution, small facets are required [9].

The software recognizes the surface structure of the object to be measured in digital camera images and allocates coordinates to the image pixels. The first coordinates are gathered already when recording the reference condition. In the measuring project, this image represents the undeformed state of the object. After or during the deformation of the object to be measured, further images are recorded. The software compares the digital images and calculates the displacement and the deformation of the object characteristics. The software controls most of the system functions. Measuring, evaluation, display and print functions are available.

RESULTS AND DISCUSSION

To investigate the chipping process, DSP has been used to evaluate the strain field. The chipping process was filmed and the current value of the load was recorded by the software. An evaluated series of pictures was selected and are shown in figure 4, the load for the actual stage are illustrated in the load-time diagram on the right hand of the stage picture. The load increases as the knife penetrates the wood sample to a maximum and decreases when the chip crack is initiated.

The cracking process takes place before the crack actually initiates, and the value of the shear is increasing in the plane where the crack will initiate. Just before the crack is initiated the shear is reaching a maximum in a point close to the knife-edge. The shear increases as the force increases, and when the crack is initiated and starts to grow the shear concentration is following just in front of the crack tip.

In this investigation the coordinate system has not been oriented to the grain orientation. In coming investigations the coordinate axis for the system will be oriented parallel and perpendicular to the grain. In the pictures one can see shear on the face side (on the right hand of the knife) of the knife, that may be a result from the low cutting speed that gives a distribution of friction forces. The software has problem to evaluate the area closest to the knife-edge, but the results are promising and the technique will be further developed.

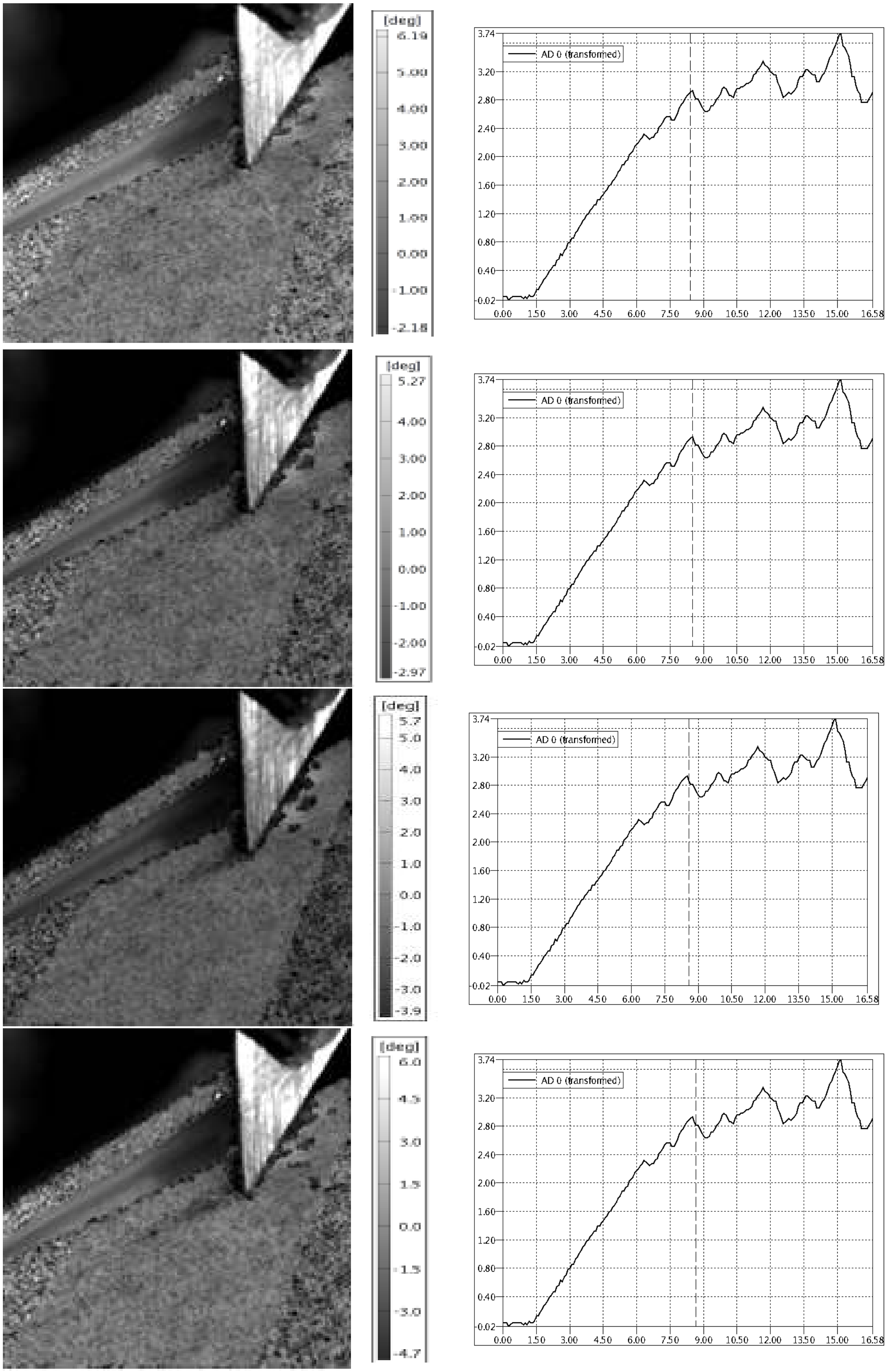

Figure 4. The shear and the force (kN)-time (s) diagram.

The process of chip formation is greatly influenced by the mechanical properties of the wood. Those that are of particular interest are the cleavage strength of the wood, the shear strength parallel to grain, and the compressive strength parallel to the grain. A higher compressive strength or a lower cleavage or shear strength will tend to produce thinner chips [14].

During the process of chip formation, compressive and shear stresses develop in a region adjacent to the knife surface, and these stresses in relation to the cleavage or splitting strength of the wood and the shear strength parallel to the grain governs the chip formation [14].

CONCLUSIONS

The present method is aimed as a tool for studying the deformation processes that are active during chip formation. The preliminary results given here indicate that the chip formation can be observed and evaluated. A series of photographs were taken from the area close to the knife-edge during chipping. The quality of the frames is sufficient for investigation of the deformation and fracture process and the evaluated data can be used in FE-modelling. The experimental method is promising but needs some improvement regarding resolution in the optical measurement closest to the knife-edge.

FURTHER WORK

The present study is a part of a larger project and the experimental results will be the basis for future FE-modelling.

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