A Method for optimising the positioning of boards in glulam-like products

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In glued-laminated-timber or similar products, strength-reducing features are randomly distributed. It is therefore probable that weak spots in adjacent boards may accumulate (Fig. 1a). However, such local accumulations of weak spots could be diffused by a relative shift between single boards (Fig. 1b) so that the probability of low strength values decreases. The study reports on a machine-based identification of growth defects and the quantification of their corresponding defect parameters. Based on these data, algorithms were developed to optimise board positions in glulam-like products.

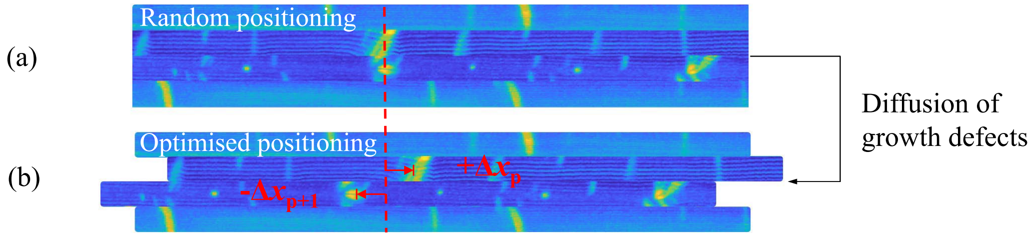

Figure 1: Illustration of random (a) and optimised relative positioning (b) of four boards each

The defect parameters Knot Area Ratio (KAR) and Slope of Grain Angle (SOG*)* were quantified on a suitable small scale. This was based on raw data from a strength grading machine Goldeneye 706 (density map, surface grain angle map) supplied by MiCROTEC Srl. A method for an X-ray based quantification of KAR-like knot area ratios was investigated. The underlying principles of a knot detection from density variations and the description of a Knot Depth Ratio (KDR) were adapted from Oh et al. [1]. According to their definition, KDR = 0 refers to the clear wood matrix, KDR ∈ (0,1) to knots partially penetrating the clear wood matrix and KDR = 1 to knots fully penetrating the clear wood matrix. The KDR was herein determined for every pixel of the density map. The $i \times j$-sized KDR-matrix was then processed into a $n \times m$-sized KAR-matrix for approx. $\frac{i}{n} \times \frac{j}{m}$ -sized cells. For this, maximum values of KDR along the length index j were identified within every cell and averaged along the width index i of every cell leading to a projected cross-section. SOG parameters were determined using laser scan data from the corresponding Goldeneye 706 module. The module measures horizontal SOG on the faces and vertical ones on the edges of the boards. The thus given surface grain angle map was processed in accordance with Rais et al. [2] by determining mean spatial SOG for every cell. For that, horizontal and vertical SOG were interpolated and converted into spatial SOG. Both, KAR and SOG, were then normalised and combined into the normalised parameter (NP) using Eq. (1). The NPs of adjacent cells were then summarised to a penalty value PEN by Eq. (2) where high values of PEN represent accumulations of growth defects. PEN is a weighted sum of NPs of adjacent cells in length and width dimension. It thus pragmatically considers stair-like fracture patterns through adjacent boards due to an offset of weak spots. PEN values were being calculated for every permitted positioning of each board within the product (= shift configuration). Possible degrees of freedom for the positioning of the boards include: relative shift (*x*-axis), relative rotation (*z*-axis and/or *x*-axis). As preliminary studies showed the best optimisation effect using relative shifts, this method was pursued.

$$\mathrm{NP}_{k,p} = \frac{\mathrm{KAR}_{k,p}}{\mathrm{KAR}_{0.95}} + \frac{\mathrm{SOG}_{k,p}}{\mathrm{SOG}_{0.95}} \quad (1)$$

$$\mathrm{PEN}_k = \sum_{p=1}^{n} \sum_{\Delta k=-2}^{2} \beta_{|\Delta k|} \cdot \mathrm{NP}_{k+\Delta k,p} \quad (2)$$

Herein, indices (k, p) are controlling variables of (n, m), $\mathrm{KAR}_{0.95}$ is the 95th percentile of the KAR distribution function, $\mathrm{SOG}_{0.95}$ is the 95th percentile of the SOG distribution function and $\beta_{|\Delta k|}$ is the weighing factor of the $(k + \Delta k)$-th cell column with $\beta_{|\Delta k|=0} = 1$, $\beta_{|\Delta k|=1} = 0.5$ and $\beta_{|\Delta k|=2} = 0.25$.

The optimised positioning is found by identifying the shift configuration, where its weakest cross-section (= occurrence of PEN_{max}) holds a lower PEN_{max} than the weakest cross-section of every other shift configuration. 1000 preliminary simulations of relative shift configurations showed a possible decrease of PEN_{max} by approx. 10 % using a maximum relative shift restriction of ± 10 cm with source boards 4 m in length.

References

[1] Oh, J.-K., Kim, K.-M., & Lee, J.-J. Development of Knot Quantification Method to Predict Bending Strength Using X-Ray Scanner. Mokchae Konghak 36(5) (2008), 33-41.

[2] Rais, A., Bacher, M., Khaloian-Sarnaghi, A., et. al. Local 3D fibre orientation for tensile strength prediction of European. Construction and Building Materials 279 (2021).