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Explicit Analysis of Cyclic Fatigue Behavior of Poplar Wood Pallet by Computational Engineering — Von Mises Yield, Goodmen and N-S Diagram Approach

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Wood pallets are important carrying tools, defined in packaging engineering, for fragile or any kind of heavy goods. Wood pallets are exposed to flexural forces resulting in fracture and fatigue during transportation. In this research, the fracture and fatigue behavior of wood pallet system under loading was investigated, taking into account nail and pallet material behavior, using strain-stress distribution by computational finite element analysis. Static and dynamic numerical analysis was performed on the 3D model of poplar wood pallet using ANSYS computational system. To validate the data gathered from Von Mises yield, Goodman and N-S fatigue diagrams were established to predict fatigue life. The finite element models built in this research may assist the design engineers and manufacturers in evaluation of new design strategies of poplar wood pallets.

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1. Introduction

In modern transport packaging, safety, damaging and loading failure of products, are the results of poor pallet design. These failures cause enormous inefficiencies in the supply chain. The trend towards lightweight constructions of wood pallets may be considered as one of the main features of modern technology development in transporting or carrying tools. Poplar wood is essentially a natural fiber-reinforced composite [1]. It has a cellular, low mass structure that performs well under loading and its mechanical properties are greatly dependent on moisture content [2]. Fatigue of wood pallet materials is a routine drawback of members or structures that are exposed to regularly executed loading [3]. Literature of fatigue performance and tolerable design of wood pallets stresses is very limited and very little research has been carried out on the poplar wood pallet's fatigue response in computational engineering [4, 5]. Failure of material under cyclic or fluctuating loading conditions is identified as fatigue failure. Crucially, such failure can happen well below the eventual static strength of the wood material. Time dependent failure is considered as a cyclic fatigue failure. The failure is related mainly to recurring cyclic stress, from a maximum to a minimum value, produced by an alternating load [6]. The value of instantaneous plastic deformation of poplar during compression perpendicular to grain is not proportional to the value of constant stress under the conditions of a wide range of the constant stress, various temperatures, and moisture content [7]. Hence, the performance of wood pallets under both cyclic and static load and permissible design stresses for wood pallets are important for the efficient carriage and safe design of goods [7]. In this study, poplar wood pallets were constructed by joining in a nailing machine, since such pallets were the focus of this research, dealing with simulated fatigue behavior.

2. Computational engineering analysis for fatigue behaviour

This research was undertaken to define (1) the fatigue resistance of poplar wood pallets and nailing, when cyclically loaded at maximum strength and (2) to assess the correlation between applied stress levels and fatigue life in range of allowed service stresses, using computational engineering. To achieve these objectives finite element simulation analysis (FEA-LS DYNA workbench) and fatigue tests were performed to estimate the fatigue strength of poplar wood pallet in specified cyclic loading conditions, according to ISO 2874 and ASTM D 6815-02a standards [2]. For the test procedures of this research a CT-5000C compression testing machine with 250 kN strength capacity was used.

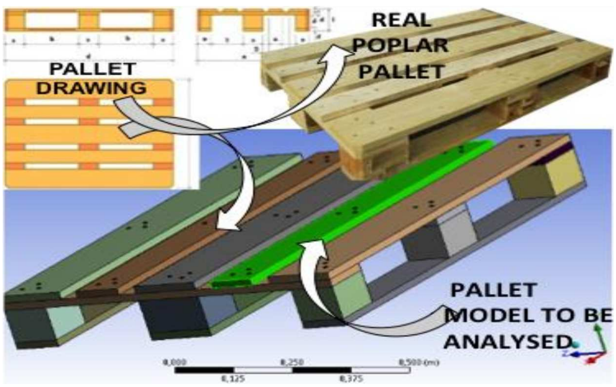

Fig. 1. Wood pallet model.

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The material and mechanical properties of nails and wood, number of nailing units and their location on pallet have been taken into account. Based on the shape and material of the prepared nail-pallet joint, nailing model was constructed. The finite element analysis was carried out to determine the stress occurring during joining process, the geometry of the nail and the rigidness of the wood material. Initially mean stresses were analyzed during nailing process by finite element analysis. A poplar wood pallet was modeled in SOLIDWORKS program, as shown in Fig. 1.

The existence of anisotropy of wood means that shear and cross-grain stresses should be avoided, so the lay-out should be such that the principal axis of loading is along the longitudinal (or growth) direction [3]. Wood is weaker during compression than tension [6], thus compressive loading is the dominant factor in pallet design [8]. Its low density and low strength mean that thick sections have to be used, providing excellent buckling resistance. The finite element method was applied to poplar wood pallets, to examine the behavior of the fatigue under the external loads, which cause displacements the upper part of the pallet face. Interaction forces arising during nailing were then analyzed for maximal stress zones in which the mid face may primarily be subject to destruction displacement along Z axis, as presented in Fig. 2. Von Mises stresses inside the pallet under different forces were simulated to analyze minimum and maximum stress plasticity.

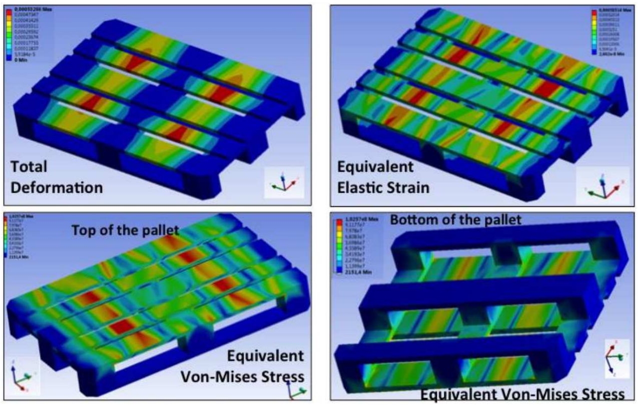

Fig. 2. The stresses and strains during nailing of a pallet.

To observe the propagation of elastic stresses in poplar wood pallet, a numerical wave simulation was developed using the finite-element computational system ANSYS, as shown in Fig. 2. The simulation was performed as a dynamic analysis that has quantified nodal displacement and the velocity of wave propagation through poplar wood pallet.

To control the poplar wood pallets fatigue resistance when cyclically loaded at identified amounts of maximum strength, laboratory tests were realized to represent the distribution of the hazards. Wood pallet fatigue testing requires the stress information which may be obtained from work hazards observed in practice, shown in Fig. 3.

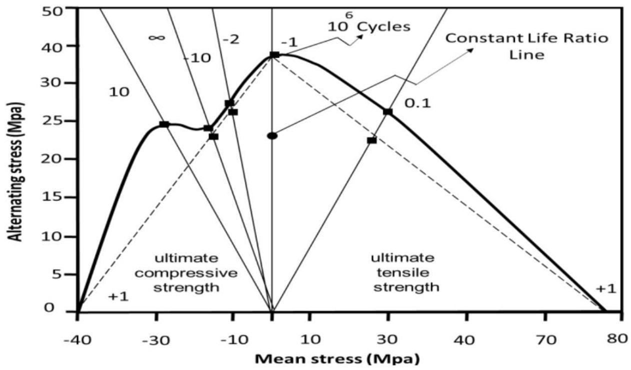

Fig. 3. Goodmen diagram for poplar wood pallet.

This environment has provided capability of reproducing stresses and damage by pallet fatigue testing under specified cyclic loading conditions. Evaluation of the connection between (1) the fatigue life and (2) the affected loading stress levels helped to build a correct model by employing these parameters to provide a realistic base for design of poplar wood pallets.

The static fatigue tests were arranged, as defined by ASTM standards, on a universal testing machine. The work involved repetitive bending, compression and reaching across the wood pallet. The research of load testing of pallets and components comprises hydraulic compression and bending testing up to loads of several tons. Critical to the success of a dynamically loaded structure is its fatigue design that relies on the understanding of fatigue behavior at all $R = \sigma_{\min}/\sigma_{\max}$ ratios. For this Goodman diagram can be used, where mean stress versus alternating stress is plotted for numerous different R ratios and bell-shaped curves representing constant lives can be constructed as shown in Fig 3.

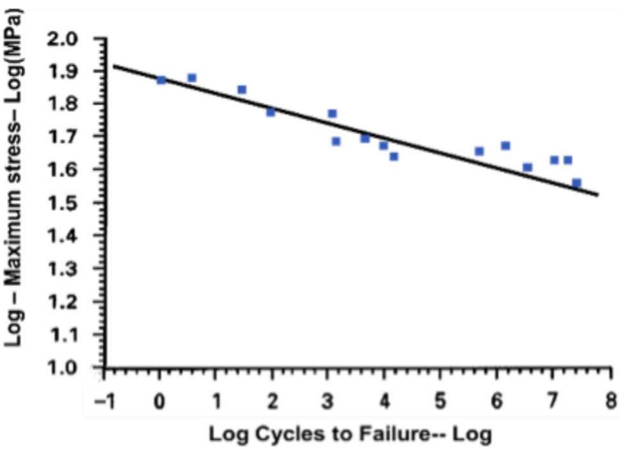

Fig. 4. Log σ-N curves of fatigue life diagram.

In this research, the entire poplar wood pallet was tested to measure fatigue life. The bell shape of the constant life diagram was taken into account by imposing a triangle with corners at ultimate tensile strength, $R = 1$ and ultimate compressive strength values, as shown in

Fig. 3. Generation of σ-N curve at $R = -1$ provides a safe estimate of fatigue life to measure reliability of the data. The fatigue level was measured as stress of 20 MPa at 1 million cycles. The triangle imposed in Fig. 3 creates a conservative constant life diagram that fits within the original comprehensive curve. Measurement of the ultimate tensile strength and ultimate compressive strength and generation of σ-N curve at $R = -1$ and statistical treatment of the data to improve its reliability have allowed the rapid generation of simplified constant life diagrams which offer a safe estimate of fatigue life. The generation of such diagrams normally requires a large number of tests of representative material to provide S-N curves from which constant life data can be derived, as given Fig. 4.

3. Conclusions

Outcomes of the research show that the examined poplar pallet material has outlasted over 1 million cycles of fatigue life at stress and strain levels equal to 35% of standard material ultimate strength. The Goodmen diagram and the S-N curve with different load directions can be constructed according to the above results. Cyclic loading tests were performed on poplar wood pallet. The cycle frequency was 30 Hz, with valley-to-peak load ratio of $R = -1$. Experimental outcomes validate that the finite element computational ANSYS modeling approach can be efficiently used to predict the deformation and fatigue life of engineered wood pallet, subjected to static and dynamic flexural loads.

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References

[1] P. Rousset, F. Davrieux, L. Macedo, P. Perre, *Biomass Bioen.* **35**, 1219 (2011).

[2] J. Mackerle, *Wood Sci. Technol.* **39**, 579 (2005).

[3] S. Vasic, I. Smith, E. Landis, *Wood Sci. Technol.* **39**, 3 (2005).

[4] M. Lukacevic, J. Fussl, *Eur. J. Wood Prod.* **72**, 497 (2014).

[5] K. Borst, C. Jenkel, C. Montero, J. Colmars, J. Gril, M. Kaliske, J. Eberhardsteiner, *Computers and Structures* **127**, 53 (2013).

[6] E. Feulvarch, M. Fontaine, J.M. Bergheau, *Finite Elem. Anal. Des.* **75**, 62 (2013).

[7] T. Tsalkatidis, *Int. J. Eng. Technol.* **3(2)**, 129 (2014).

[8] Ö. Karaçalı, A.T. Ulguel, *Acta Phys. Pol. A* **125**, 183 (2013).