Preliminary study for wood screws fatigue

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Abstract. The aim of this paper is to present some experimental and numerical results obtained for wood screw fatigue. An experimental setup was designed and made in order to evaluate wood screw failure due to fatigue. Tests were made on 6x100mm wood screw specimens. In order to validate the experimental results several numerical simulations were made. The numerical results were represented and compared with the experiments and other similar test results. The experiments reveal fatigue occurrence and a good agreement between the obtained results and those presented in literature.

1. Introduction
The use of wood has been and will permanently remain topical due to its remarkable properties: elasticity, low density, high thermal insulation and last but not the least accessibility. Wood is present in the various elements with different dimensions, from small to large such as: framings, scaffoldings, furniture or even entire houses. In all these constructions, assembling of wood elements is needed to assure a firm relative position and the newest and most widely used method is that of using wood screws. This technical solution has numerous advantages, both from the firm grip feature and the possibility of making the assembly by aid of electric tools. Unlike nailing, the use of screws offers an additional advantage in the possibility of disassembling and reassembling much easier.

Large wooden constructions are often subjected to variable loads caused by weather conditions such as the action of wind, workers motion on scaffoldings etc. Those conditions lead to relatively important variable loads on the assembling elements which could cause failure due to fatigue. The relative novelty of this wood screw assembly method has the effect of a reduced number of fatigue studies being presented in literature, which lead the authors of this paper to initiate the present research.

The fatigue phenomenon depends on load, local geometry of the machine elements, material and the residual stresses. In the present paper there are presented some results regarding wood screw failure due to fatigue at high and low level loadings. At high level loadings, material failure appears after a few cycles, phenomenon known as low-cycle fatigue (LCF) while at low loadings, the damage occurs after thousands of cycles or more, the so called high-cycle fatigue (HCF), [1], [2].

From the ‘50s, smooth laboratory specimens subjected to cycling deformations were used, [3], [4], to predict a part’s lifetime until damage occurrence. If the relationship between the localized strain and the fatigue life is known, it is possible to determine the component’s lifetime in the critically loaded region, [5]. This method is still used.
Nowadays, the evolution of the FEA software allows predicting the fatigue life of the component without experimental tests, based on material fatigue properties and geometrical and meshing models. In this regard, several papers can be found in literature, which sustain the above affirmation, [6-8].

The paper proposes an experimental study of wood screws failure due to fatigue. A wood screw-PVC cylinder assembly was used to determine the failure of the wood screw due to cyclic loading. The experimental results were used to draw the fatigue failure and to estimate the wood screw lifetime.

A numerical model was developed using specialized software, where the screw geometry and the screw-wood board assembly were simulated. The model simulates static and variable loadings. The results obtained numerically and experimentally were compared and show similar evolutions.

2. Experimental setup
An experimental setup for wood screw fatigue study was conceived and built. The sketch of the experimental setup is represented in Figure 1.

![Figure 1. Experimental setup.](image)

Several tests on wood screws were conducted using a lathe machine and an original loading device. For the experimental tests, each wood screw (1) was screwed 30 mm into a PVC cylinder (2) represented in Figure 1. The wood screw – PVC cylinder assembly was fixed on the lathe’s rotating spindle, (3). An elastic steel flat spring (4) was used for loading the wood screw. The flat spring has a bearing housing (5) and a bearing (6) mounted on one end and a clamping part (7) on the other end. The bearing is used to reduce friction torque during motion between the wood screw and the loading device. The support of the flat spring is mounted on the lathe tool post to be able to control the wood screw loading by modifying the relative position between tool post and the rotating axis of the lathe.

The loading level is measured using a plunger dial indicator (8). The loading was obtained by measuring the deformation of the flat spring. The deformation-force correlation of the flat spring was determined and represented in order to evaluate the elastic constant. In Figure 2 are represented the experimental values of deflection obtained for static bending of the flat spring.
To determine fatigue number of cycles, a magnetic sensor (9) and a magnetic part (10) were used. The magnetic part is placed on the PVC cylinder and the magnetic sensor is fixed on the lathe ground. The sensor is positioned so that the magnetic field of the magnetic part modifies the sensor state each time the magnetic piece is near the sensor. On each rotation, the magnetic piece will induce one pulse in the sensor. The sensor pulses are numbered and recorded using a numeric counter.

The test starts with the screwing process of the wood screw, 30 mm, into the PVC cylinder. Then, the loading is generated and controlled by modifying the relative position between the lathe tool post and the rotating axis. The loading is evaluated by measuring the flat spring deformation using a plunger dial indicator. After the loading was modified, the sensor, the counter and the lathe were powered on. The rotational speed of the lathe was set to 500 rpm. The tests were stopped when the plunger dial indicator showed low loading force corresponding to wood screw failure. The lathe is powered off and the number of cycles is read from the counter.

The test procedure is restarted using different loading and specimens. For each test the screw failures appear in the same region as is shown in Figure 3.a and the rupture surface was presented in Figure 3.b.

![Figure 2](image)

**Figure 2.** Experimental values of the elastic flat spring bending deformations under static loading.

![Figure 3](image)

**Figure 3.** a) Damaged wood screws b) Wood screw fatigue surface.
Several tests were made and the results are represented graphically in Figure 4.

![Figure 4](image)

**Figure 4.** Force vs. number of cycles for 6X100mm wood screw failure.

Since the wood screws is not a mechanical element for which a fatigue calculus is typical, we consider that a force-number of cycles diagram is more significant for the user and for the appreciation of the risk involved by using these elements. In literature there are presented such representations, [9].

The experimental results reveal that the wood screw LCF failure appears at loads above 200N. Under 100N the wood screw resists for tens of thousands cycles and can safely be used for general purposes.

The load - number of cycles correlation curve has an evolution similar to those presented in literature, [1].

3. FEM analysis

The geometry of a 6x100 mm wood screw mounted on a cylindrical piece was modelled in Autodesk Simulation software. The shape and dimensions of the wood screw were similar to those used in experimental investigations.

In order to estimate the wood screw material, the steel composition was investigated in order to determine if alloying elements are present. Three tests were made using a PMI MASTER PRO spectrometer produced by Oxford Instruments. The tests reveal that the specimens were made from low carbon steel (approx. 0.08% C). The wood screw was considered as being fabricated from *AISI 1020*, (E=200 GPa, v=0.29). The cylindrical part is made from a polymeric material (E=4.528 GPa, v=0.428).

The boundary conditions for the model were chosen to simulate the experiment. The loading was applied on the side of the wood screw head and the nodes on the side faces of the cylinder were considered fully fixed. A static analysis was made to determine the deformations and the stresses generated in screws. Figure 5 represents the von Mises stress distribution obtained for a load of 127N.
To validate the screw material and geometry, the deformation of the wood screw was investigated and represented in Figure 6. The results reveal that at 127 N loads, the wood screw has a deflection of 3.89 mm. The experimentally obtained dependency between static load and bending deformation magnitude of the elastic flat spring which generates the wood screw strain was previously shown in Figure 2. The experimental investigations yielded a bending of the flat spring at 127N of 5mm. The differences between the experiment and the numerical simulation could appear due to material heat treatment, residual stress and the wood screw – cylinder contact stiffness.

In order to evaluate the wood screw fatigue life, several fatigue analyses were made at different loading levels and the results are represented in Figure 7 and Table 1. For loads under 100N, a long lifetime for screws was obtained. At loads higher than 100N, the screw’s lifetime decreases rapidly and the LCF appears. The most loaded region is near the cylinder’s front surface.
Figure 7. Results obtained for wood screw fatigue lifetime at several loadings.

Table 1. Wood screw FEA results.

| Force [N] | Wood screw bending deformation [mm] | Wood screw lifetime [cycles] |
|-----------|----------------------------------|-----------------------------|
| 40        | 1.22                             | 55126                       |
| 51        | 1.87                             | 17279                       |
| 76.5      | 2.46                             | 3277                        |
| 102       | 3.11                             | 1202                        |
| 127.5     | 3.87                             | 570                         |
| 178.5     | 5.43                             | 173                         |
| 229.5     | 6.98                             | 73                          |
| 280.5     | 8.54                             | 38                          |
| 355.7     | 10.85                            | 18                          |

The experimental and the numerical values correlations obtained for fatigue failure were represented graphically in Figure 8. Both curves have similar evolution but differences appear due to contact stiffness between bodies and residual stress in wood screws. Those two factors weren’t considered in FEA. Also, own results were represented on the same chart and compared with those presented in ref. [10]. Ref. [10] and own results are disposed approximately on the same curve.
4. Conclusions
Wood screws are usually used to fix and assemble furniture and other home structures. Often, the wood screws suffer damages during the screw driving process due to high friction between surfaces and lack of axial screwing force. Due to this, it is important to determine wood screw fatigue failure in order to avoid accidents or damages.

To estimate the wood screw lifetime, some experimental tests were conducted and the results can be used to evaluate the maximum loading force taken over by screw. A special setup was conceived and built. Several tests were made and the results were presented graphically. The tests reveal that the specimen’s failure (6x100mm wood screws) occurs after few cycles at loads above 200N and the screw reliability increases under this value.

In order to validate the experimental results for wood screw fatigue, some numerical simulations were made. The wood screw-cylinder assembly was constructed in Inventor software and then, the model was exported in Simulation Mechanical software. To obtain the fatigue failure of the screw, a static and a fatigue analysis were required. First, the static analysis was made and the obtained numerical results were used as input data for the second analysis. For each loading level, another simulation was made. Using this method, nine loading levels were considered between 40 and 355N. The results were used to evaluate the experimental values obtained for fatigue. Both series of values were represented on the same chart.

The experimental and the numerical curves showed similar evolution. Differences could appear due to material heat treating and residual stress.

The results show that at loads higher than 200N the wood screw failure appears after a few hundreds of cycles while at load levels below this value the screw’s reliability increases rapidly.

Failure due to fatigue for this type of screws can appear at loads lower than those usually supported, which doesn’t recommend them for using in scaffolding assemblies.

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