EVALUATION OF THE TRANSVERSE STRENGTH OF REED STALKS

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Abstract. Common reed (*Phragmites australis*) is a grass which has spread nearly all over the globe. It is common in many kinds of wet habitats. Common reed is a very tall grass, reaching at best the height of four meters on the coasts of the Baltic Sea. In the wintertime the straw becomes a hard, yellowish stem, which makes it possible to exploit the reed also in construction. Reed material has been exploited in many ways around the Baltic Sea for centuries. In construction, reed has been used for roof materials and heat insulation. People are increasingly focusing on sustainable development and the use of natural materials instead of plastics. The reed stem is like a natural pipe. It is already used in the production of cocktail straws. However, there is a much wider range of uses, such as toy components etc. Such applications require that the reed stem is not flattened after cutting. Likewise, the end of the stem must be free of sharp edges and smooth. In previous studies, non-destructive cutting of reeds using abrasive discs was evaluated. In order to create a device for non-destructive cutting of reeds, it is necessary to know the allowable strength of the reed stalk. This paper analyses the reed straw fastening device and evaluates the transverse strength of reed stalks of different diameters. The tests were performed on reeds with a diameter of 6 to 10 mm. The developed reed straw gripping mechanism ensures non-destructive fixing of the straw during reed cutting, if the compressive force generated by the elastic clamps does not exceed the transverse compressive strength of the straw. The highest strength was found for reeds with a diameter of 9 mm, it reached 56.14 N. As the stem diameter increased to 10 mm, the compressive strength decreased slightly to 54.2 N.

Keywords: common reed, transverse strength, non-destructive cutting, gripping mechanism.

Introduction

Reed is one of the most widely distributed and highly productive wetland plant genera in the world. Since the reed is very fast growing, it is frequently cut, consequently making raw material widely available [1]. Reeds are found all over the world except Antarctica, but their main distribution is in Europe, the Middle East and America [2]. Estimates of reedbeds made in 1995 show that the global area is ~10 million hectares [3], but in Latvia, reeds grow on an area of about 13400 hectares, in more than 129 water bodies [4; 5].

Since prehistoric times, reed has been used by humans in construction applications. For instance, the reed has been traditionally used for roof hatching [6; 7].

Nowadays, common reed has been used for different purposes since ancient times. These uses include thatching the roofs, covering the walls of houses with reed, fodder for cattle, etc. The time of reed harvesting should be chosen according to the intended use of the reeds. Due to the high moisture content of reeds in summer, they are suitable for fermentation (e.g., biogas production) and as feed for livestock without further processing. In the winter season, when the stems are dead and dry, they are suitable for the production or burning of products [2].

Construction reed can be harvested in December and January, when the reed is dry and the leaves have fallen off, the soil is frozen and water bodies are covered with ice. For instance, reed cannot be cut when there is a lot of snow in winter, the thickness of the ice layer on the water bodies is insufficient, there is strong wind or it is snowing or raining [8].

In cases where reeds are used in construction as a thermal insulation material or as one of the components in the production of briquettes or pellets, it does not matter whether the structure of the reeds is deformed or not, however, when reeds are used in various decorations, essentially the cut and the cut section of the reed itself is not deformed. Therefore, continuing the study on the use of different cutting tools for reed extension, it is necessary to establish the minimum non-destructive compression values to be used in the reed gripper modelling process.

Many researchers have studied the tensile, bending and shear strength of reed stalks and roots, depending on the diameter of the reed [9-12]. Studies on strength, elasticity modulus and shear modulus for grasses have also been performed [11]. Tangential stress deformations of aluminium pipes have also been studied, considering the effect of friction [13].

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The transverse force test in the studies has been performed on concrete pipes using the Three-Edge-Bearing test, Fig. 1, developed at the Iowa State University as an easy and inexpensive way to determine the minimum strength condition for pipes [14].

Research was carried out at the Institute of Mechanics of the Latvia University of Life Sciences and Technologies to determine the longitudinal and transverse compressive strength of hemp stalks by compressing samples between two parallel planes [15].

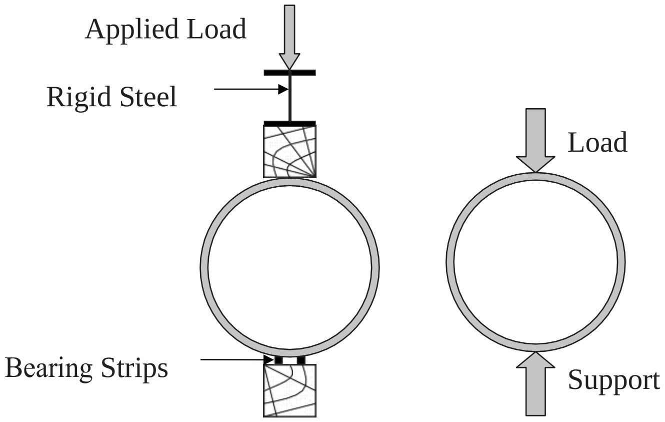

Fig. 1. **Three-Edge-Bearing test and associated pipe loading [14]**

In order to realize the non-destructive cutting of the stem, a reed fixing device was developed at the Institute of Mechanics. To determine the maximum values of the compressive force of the jaw of the device, it is necessary to know the transverse strength of the reed stalk. The aim of this study is to determine the transverse strength of the reed and its change depending on the stem diameter.

Materials and methods

Common reed was collected from the stock of Gulbju pond in Jelgava. The plant samples were collected by hand in January. The selection was carried out on location, with excluding reeds which exhibited mechanical damages, deformations or diseases. The chosen specimens were then transported to the Measurement laboratory of the Institute of Mechanics of the Faculty of Engineering of the Latvia University of Life Sciences and Technologies.

The obtained reeds were cut into sections of 30 mm. In turn, the samples of reed sections were divided into 5 groups (6 mm, 7 mm, 8mm, 9 mm and 10 mm), depending on the diameter. The air-dried reed had the average moisture content approximately 10% at the time of the compression tests. The reed stem outer diameters were measured using a digital caliper with resolution 0.01mm. The variation of the diameters of each group of the samples did not exceed ± 0.2mm. Transverse strength tests were performed on common reed to determine the maximum force with which the reed can be gripped with the reed gripping mechanism. Triangular reed mounts (Fig. 2.) were designed to simulate the reed gripping mechanism.

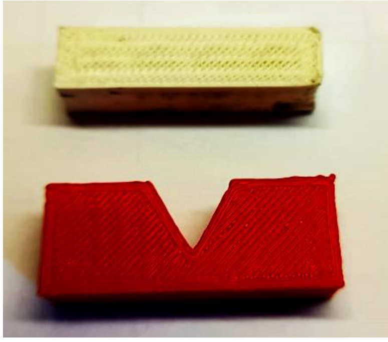

Fig. 2. **Triangular reed mounts**

Transverse strength of reed stalks was assessed with using an Instron 5969 universal testing machine, with a measurement range of strength values up to 50 kN. The maximum measurement error of the equipment is 0.1%. Average force measuring accuracy did not exceed ± 0.5%.

The specimens were placed between the fixtures, one of which was flat and the other formed with a cut-out at an angle of 60 degrees, Fig. 3. In this way, the distribution of forces in the jaws of the developed mechanism was simulated. Figures 4 and 5 show the location of the sample in the test rig before and after shattering.

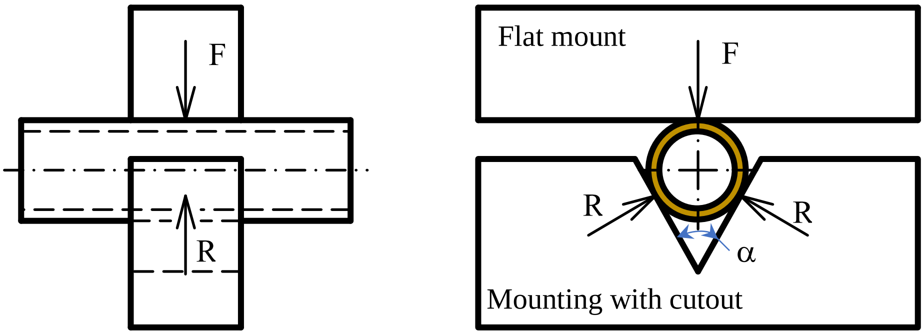

Fig. 3. **Points of application of force *F* and reactions *R*, α – cut-off angle, α = 60°**

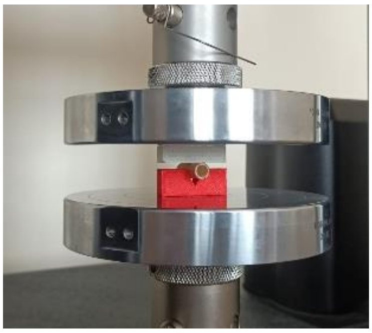

Fig. 4. **Common reed section before loading**

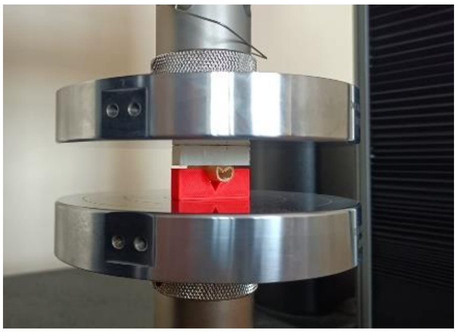

Fig. 5. **Common reed section after loading**

During the compression process, the specimen deforms until the internal forces exceed the strength limit of the stem. Fragment collapse occurs only in the upper part, as shown in Figure 5. This can be explained by the fact that in the lower part, in addition to the support reactions, there are also frictional forces, which slightly reduce the stresses in the material.

Results and discussions

Some applications require that the reed stem is not flattened after cutting and the end of the stem must be free of sharp edges and smooth. To ensure that the shape of the reed is maintained during cutting, it is possible to use cutting with an abrasive disc. It is necessary to rotate the stem to avoid tearing the outer fibres of the stalk during cutting. A gripping mechanism was developed to secure the reed in the cutting device (Fig. 6).

The stem rotation mechanism consists of a gear 3 to which three levers 6 with clamps are attached to secure the reed. The gripping force of the reeds is provided by a ring 4 of elastic material that tightens the clamps together. Releasing the reed from the grip is ensured by reversing the drive motor 1. As a result, the ratchet 5 is blocked and the clamps release the reed. Sufficient torque is required to ensure stem rotation during the cutting process. When the straw is compressed in the jaws, the torque is provided by the frictional forces acting at the point of contact between the straw and the pawl. The magnitude of the frictional force depends directly on the compressive force, so it is necessary to know the maximum permissible force of the stem when the resulting torque can be estimated. In order to calculate the compression mechanism, it is necessary to determine the required reed compression force. The compressive force must not exceed the transverse strength of the reed.

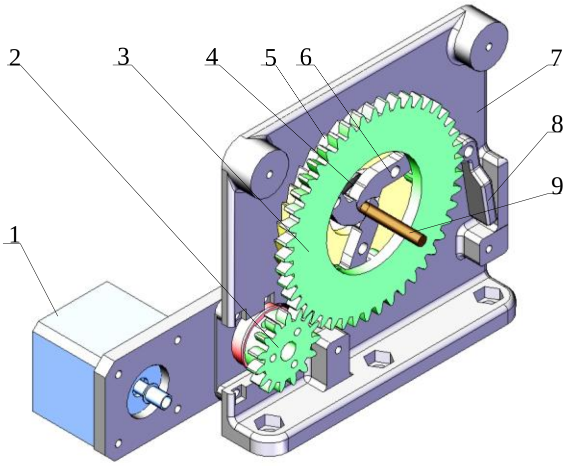

Fig. 6. **Common reed grab mechanism**: 1. Drive mechanism, 2. Drive gear, 3. Driven gear, 4. Rubber ring, 5. Ratchet-wheel, 6. Lever, 7. Housing, 8. Pawl, 9. Common reed section

The scope of investigation was to find the compressive durability of reed stalks in lateral compression depending on the stalk size. The obtained values of the compressive strength further will be used for modelling of the non-destructive cutting process.

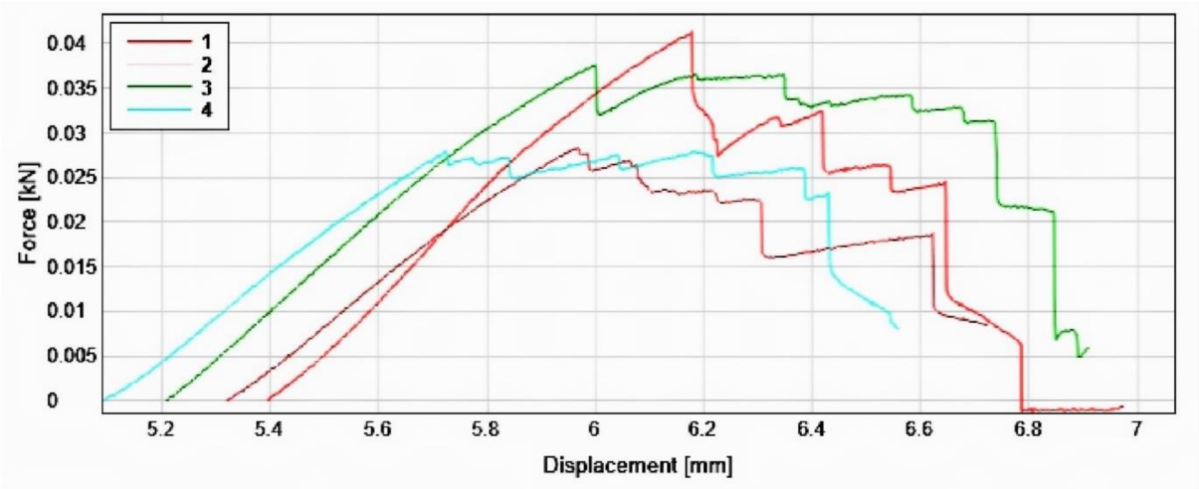

Fig. 7. **Force-displacement diagrams of sample destruction**

As a result of the experiments, reed stalk collapse curves were obtained (Fig 7). It can be seen that with the increase of the loading force, the elastic deformation of the stem occurs. When the strength limit is reached, the material collapses rapidly. As the deformation continues, the stem breaks in several places. The first deflection point, which characterizes the maximum load force, was taken as the strength limit.

As a result of the research, the maximum force that can be tolerated by reed stalks of different diameters was determined.

The obtained results show that the strength of the stem increases with increasing diameter (Fig. 8). The lowest strength was found for stems with a diameter of 6 mm. The average strength of such stalks reached 28.9 N. As the diameter of the reed increased, the strength increased, reaching a maximum value for stems with a diameter of 9 mm. The strength of these stalks reached 56.14 N, which is almost twice as much as that of reeds with a diameter of 6 mm. The strength of reeds with a diameter of 10 mm was slightly lower compared to 9 mm reeds. This can be explained by the fact that in the process of fracture, the stresses in the stem are determined by the bending moment caused by the force. The stresses in the material depend on the ratio of the thickness of the stem wall to its diameter. As the stem diameter increases, this ratio decreases. In order to prove this hypothesis accurately, it is necessary to perform additional experiments with larger stem diameters and evaluate the ratio of wall thickness to its diameter.

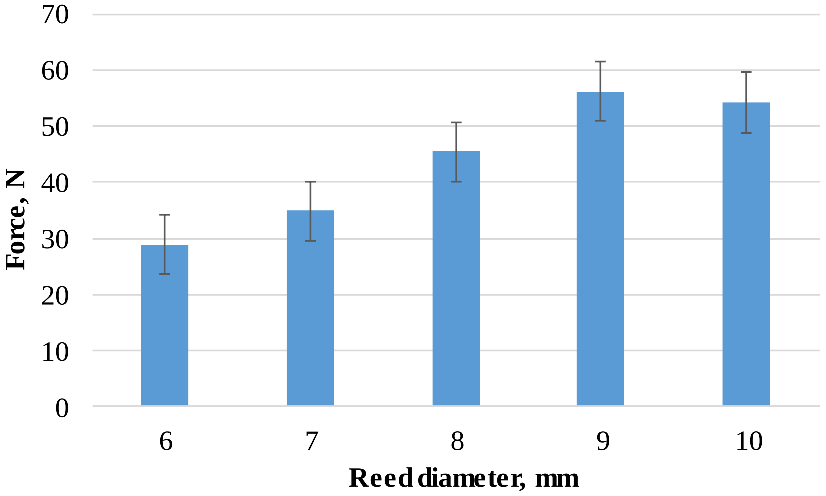

Fig. 8. **Dependence of the breaking force of the sample on the diameter of the stalk**

Microsoft Excel is used to carry out the statistical analysis of the results. The trend line, equations describing the trend line, and the value of R² (determination coefficient) were determined. The standard deviations were calculated.

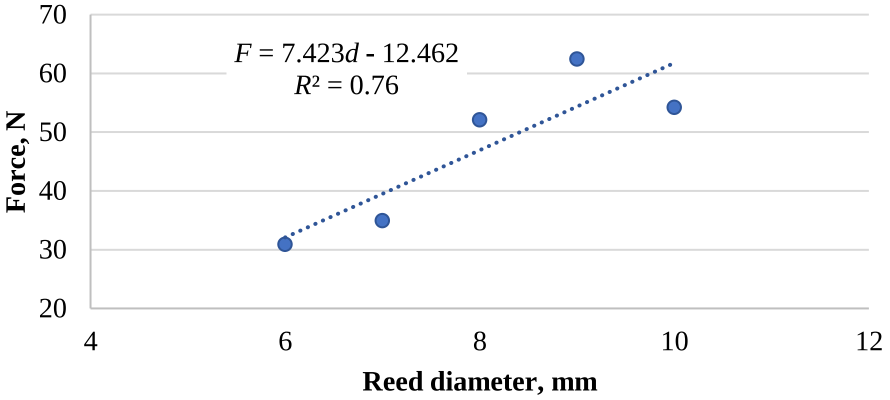

Fig. 9. **Relationship between the compressive force and the diameter of common reed**

The coefficient of determination shows that the applied force depends on the diameter of the reeds by 76%.

Analysis of variance (ANOVA) was used to analyse the differences between the groups. The results of the statistical analysis of the data are summarized in Table 1. The null hypothesis that the average applied force did not depend on the reed diameter was rejected and the alternative hypothesis that the average applied force depends on the reed diameter was accepted.

Table 1

Analysis of variance (ANOVA)

Source of Variation	*SS*	*df*	*MS*	$F_{fact.}$	*P*-value	$F_{crit.}$
Between Groups	9395.682	4	2348.92	**7.548998**	5.4E-05	**2.525215**
Within Groups	18669.39	60	311.1566	-	-	-
Total	28065.08	64	-	-	-	-

After performing the analysis, it can be concluded that $F_{fact.} = 7.548998 > F_{crit.} = 2.525215$, then with a probability of 95% the null hypothesis can be rejected and the alternative hypothesis that the average applied force depends on the reed diameter can be accepted.

Conclusions

1. The developed reed straw gripping mechanism ensures non-destructive fixing of the straw during reed cutting, if the compressive force generated by the elastic clamps creates sufficient friction force.
2. The highest strength was found for reeds with a diameter of 9 mm, it reached 56.14 N. For reeds with a diameter of 10 mm, the strength decreased slightly to 54.2 N.
3. Analysis of variance (ANOVA) showed that $F_{fact.} = 7.548998 > F_{crit.} = 2.525215$, then with a probability of 95% the null hypothesis can be rejected and the alternative hypothesis that the average applied force depends on the reed diameter can be accepted.

Author contributions:

Conceptualization, I.N.; methodology, I.N; formal analysis, A.K., O.V.; investigation, O.V.; data curation, M.S; writing – original draft preparation, O.V. and A.K. – writing and editing. All authors have read and agreed to the published version of the manuscript.

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