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Effect of Low Temperatures on the Brittle Fracture of Hazelnut Shell

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ABSTRACT

Kernels are widely used in the food industry because of their high nutritional value. The nutshell obtained by hulling is used as an absorbent. Currently, hulling is carried out without pre-treatment of the shell. However, lowering the temperature allows for reducing the material's strength. When the temperature of cold brittleness is reached, the shell's strength characteristics are reduced, which decreases the cost of breaking. To determine the tensile strength of hazelnut shells at various temperatures, the authors used the method of compressive testing. Compressive testing of materials was carried out using a PM-MG4 universal hydraulic testing machine. An Evercam 1000-8-M high-speed camera was used to determine the deformation amount. To reveal the material's propensity to brittle fracture, the samples were subjected to dynamic loading on a special installation - a pendulum-type copra. Determining the temperature of cold brittleness allowed for designing highly efficient methods of hulling and its instrumentation. The article presents methods for studying the shell's strength characteristics at various temperatures in the range from 25 to -190℃. The results for compressive strength and impact strength of the shell at different temperatures were given. The range of cold brittleness of the shell was determined. The experimental results showed that a decrease in the temperature of the shell led to a transition from mixed to brittle character of the shell's destruction at a temperature range of -40...-80℃. Lowering the shell's temperature reduced its tensile strength by an average of 25-30%, depending on the size of the nut. The obtained results can be used in the development of new methods and technologies based on them for hulling hazelnuts. The values of the shell's tensile strength can be used in the design and calculation of equipment for breaking.

1. INTRODUCTION

Nuts are widely used in the food industry, especially in the confectionery production, where roasted nut kernels serve as a raw material for praline sweets, confectionery masses, fillings, etc. [1-3]. Nuts are gradually becoming more and more popular in the dairy industry, especially in cheese production, where roasted and chopped nut kernels are added to soft cheeses in order to increase their nutritional value and flavor [4-6]. Nut oils are also used in the food industry and cosmetology [7]. A systematic intake of roasted nuts increases the nutritional value of human diet [8].

Hazelnuts are extremely popular in the food industry [9-11]. In Russia, they are cultivated in the Crimea, Transcaucasia, and the Caucasus. The kernel - shell ratio of hazelnuts ranges from 45 to 55. Hazelnut kernels are rich in amino acids and vitamins [12-14].

Uncultivated hazel shrubs (*Corylus*) grow in the wild in some parts of the Russian Federation. Their nuts are similar to commercial hazelnuts in appearance, chemical composition, taste, and aroma, but much inferior in quality. Their commercial use is constrained by the lack of efficient cracking technologies because they are much smaller than cultivated hazelnuts and have a lower kernel/shell ratio. They are difficult to process because kernels often get crashed during cracking [15-19].

For all kinds of nuts, the first stage is cracking, or shelling, or hulling, i.e., removing the shell to obtain the undamaged kernel [20-22]. This primary processing stage is usually carried out at small harvesting enterprises, which value the economic efficiency and are eager to lower the technological and transport costs while maintaining the maximal productivity and flexibility [23].

Cracking means removing the shell by cracking the nut. The destruction of the nut shell includes the following stages: incipient submicroscopic cracks, their propagation, and the macroscopic break of the shell into parts.

Shell destruction is achieved by cutting, splitting, crushing, breaking, abrasion, free and constrained impact, etc. [24].

Most industrial nut crackers crush nuts between two rotating rollers, or between a roller and an unmoving surface. However, their efficiency remains below 1-1.5% [25, 26].

The strength theory has two directions of destruction: (1) by separation or chipping as a result of tensile stresses and (2) as a result of shear pressure. Unlike the second one, the first one does not involve any noticeable preliminary plastic deformation. The destruction by separation is usually accompanied by brittle fracture, while the destruction by shearing involves ductile fracture.

The nature of these destruction types is determined by the incipient crack and its subsequent propagation. According to the mechanism of crack formation, brittle and ductile fractures are fundamentally similar.

However, the development of a ductile crack involves a significant plastic flow in the fracture composition, while the development of a brittle crack involves minimal plastic deformation [27]. In brittle fracture, the fracture energy goes on overcoming the forces of attraction between atoms on both sides of the crack and, consequently, on the development of an additional interface [28]. In the case of ductile fracture, much more energy is spent on plastic deformation than on overcoming the forces of attraction between atoms. Thus, the direction of plastic deformation usually depends on the conditions for the movement of dislocations in the region of the growing crack [29, 30].

The nut hulling process has low energy efficiency, and the efficiency of the equipment is not high. In addition, kernels are often damaged during hulling, which is a disadvantage of many designs [31]. This is due to the different strength limits of the shell and different geometric sizes. With a decrease in the size of the nut, its tensile strength can increase several times.

One method to reduce the shell's strength is to reduce its temperature making it brittle [32]. The effect of low temperatures on the destruction of metals has been well studied [33, 34]. The main factor influencing the tendency to cold brittleness is the type of crystal lattice [35]. Metals with a body-centered crystal lattice are susceptible to brittle fracture at low temperatures [36]. The nutshell is not homogeneous in its composition and shows a tendency to cold brittleness [37]. However, this property is poorly studied and there are no open-source materials confirming it. There are also no studies on cold brittleness temperatures.

This property of the nutshell would significantly reduce its tensile strength, increasing the efficiency of hulling equipment.

The aim of the research was to study the effect of low temperatures on the brittle fracture of hazelnut shell. The study presents methods for studying the shell's strength characteristics at different temperatures. The results of the research and the applicability of these strength characteristics are presented.

2. MATERIALS AND METHODS

The study involved mature intact hazelnuts of the same size and shape. The samples were divided into three groups with the following average sizes: 7, 10, and 15 mm. All the samples had the same initial moisture content of 6%, which was preliminarily determined on an A&D ML-50 moisture meter, and then the samples were placed in a desiccator.

The temperature conditions were 25, 0, -10, -20, -40, -80, and -190°C. To achieve the temperatures of 0, -10, and -20°C, the samples were subjected to thermostating for 2 h in a LiebHerr LGT2325 freezer. The temperature of -40°C was achieved in a LiebHerr LGT2325 freezer, while a SUFsg 7001 MediLine freezer was used to cool the samples to -80°C. The extreme temperature regime of -190°C was achieved by thermostating the samples in liquid nitrogen for 20 min [38].

The compressive tests employed a universal hydraulic testing PM-MG4 machine with the maximal developing force of 1 kN. This machine is usually used to test construction elements and materials. The frequency of dynamic load varies from 3 to 12 mm/min, and the permissible error under static loads is 1% of the measured load.

An Evercam 1000-8-M high-speed camera determined the deformation scale.

The experimental research methodology was as follows. At a given temperature, five nut samples from each group were placed on a special centering device installed on the testing machine. The deformation process continued until the shell cracked. The breaking load of the nut shell was determined by the force meter. The compressive strength was calculated after determining the surface area of the destroyed shell.

The deformation value was measured by high-speed filming of the experiment from the moment the pusher came into contact with the shell to the moment the shell was destroyed.

The average values were calculated based on the five samples in each group.

To determine the resistance of the nut shell to brittle fracture, the experimental conditions were as close as possible to stimulating this type of destruction. The nutshell was subjected to a dynamic load on a pendulum impact tester, where the shell was destroyed by a free-falling pendulum head, i.e., by high-speed deformation.

The experimental research methodology was as follows. First, we determined the idle energy loss of the pendulum. Next, we placed the samples on the platform of the impact tester and cracked them. The energy costs for destruction were determined by subtracting the value of the idle energy from the value of the destruction energy [39, 40].

3. RESULTS AND DISCUSSION

A series of experiments made it possible to determine the compressive strength of hazelnut shells of various initial sizes. Figure 1 shows a diagram in the F-Δl coordinates. It shows that, regardless of the initial size, the shell behaved as a brittle material.

The shell cracked where the concentration of stresses was the highest through the initiation and propagation of cracks, which eventually led to the destruction. Cracks originated and developed in places where the structure of the material was imperfect, e.g., with defects, foreign microscopic inclusions, microcracks, etc. The larger the surface of the shell, the greater the likelihood of such defects. This fact may explain why the compressive strength was more important for smaller nuts than for those with a larger surface area.

Figure 2 shows a histogram of compressive strength values for samples with an average diameter of 10 mm at various shell temperatures.

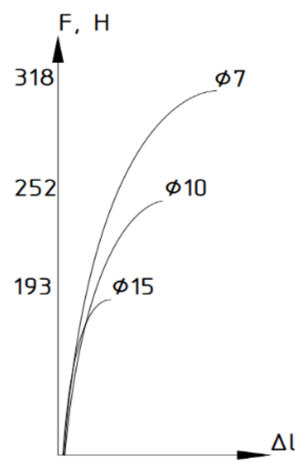

Figure 1. Compression of samples with various average diameters

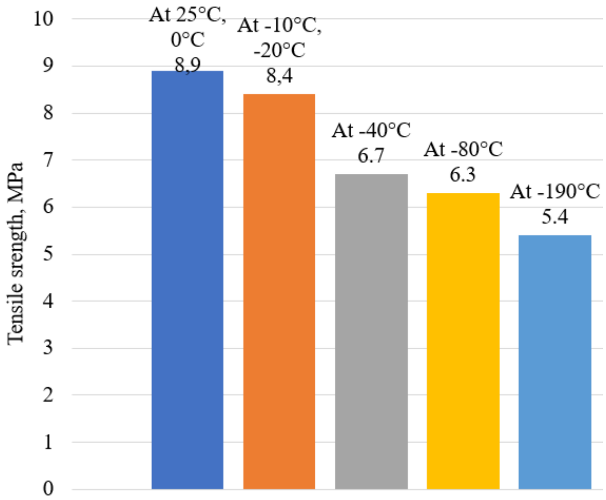

Figure 2. Compressive strength values for samples with an average diameter of 10 mm at different shell temperatures

The obtained values proved that the tensile strength of the nut shell decreased following the decrease in temperature. At 25°C and 0°C, the tensile strength values were close and maximal, compared to other temperature ranges. At -10°C and -20°C, the tensile strength was also the same and slightly below the tensile strength at higher temperatures. A more significant reduction in shell strength occurred at -40°C … -80°C. Within this temperature range, the tensile strength did not change significantly.

As the temperature dropped, the destruction occurred with almost no preliminary deformation, which means that the brittleness reached its maximum under the simulated conditions. This value was reached at -190°C, when the compressive strength of the nut shell was 5.4 MPa. The difference in the tensile strength of the frozen nut shell and the control was 3.5 MPa, or 40%.

Figure 3 shows a histogram of the compressive strength values at -190°C for samples with different average diameters.

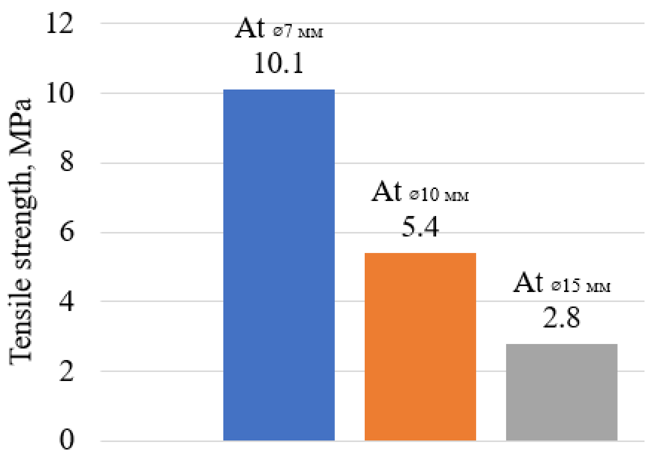

Figure 3. Compressive strength values at -190°C for samples with different average diameters

Thus, as the temperature decreased, the compressive strength values also decreased, despite the difference in sample size. However, the samples with a larger surface area had a much lower tensile strength at lower temperatures. The nut diameter of 15 mm corresponded with the tensile strength of 2.8 MPa, and the average value for this diameter was 5, 4 MPa.

Mixed fracture occurred at high and medium temperatures during compression because the ductile fracture at the initial stage ended up with the transition of the material to a brittle state. The gradually increasing stress exceeded $\sigma_{critical}$, and the ductile crack became brittle. At the final stage, the fracture proceeded according to the classical brittle pattern. The fracture had a classical brittle character at low temperatures. Thus, the nut shell had cold brittleness, which means it was prone to the manifestation or intensification of brittle fracture at low temperatures.

To determine the value of the transition to the brittle temperature range, we used the pendulum impact tester [41-43], because this method is extremely effective in stimulating brittle fracture [44, 45].

Figure 4 shows a histogram of impact strength values for samples with an average diameter of 10 mm at various temperatures.

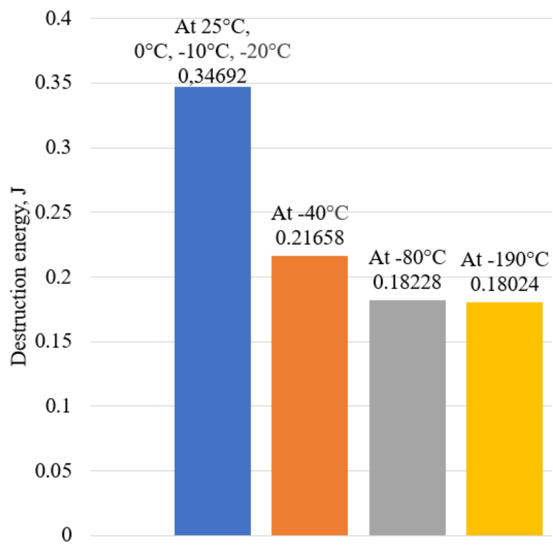

Figure 4. Impact strength for samples with an average diameter of 10 mm at various temperatures

The hazelnut shell transferred to a purely brittle state at -40...-80°C, and the tensile strength of the shell in this temperature range served as indirect evidence. The close values of impact strength and ultimate strength at -40...-80°C made it possible to make the following conclusion. In order to reduce the cost of the destruction process and increase its efficiency, it is enough to lower the temperature of the hazelnut shell to -40°C, which is enough to transfer the nut shell to a purely brittle state.

Our results allow evaluating the economic efficiency of hulling nuts at low temperatures. Lowering the temperature of the nut to -40°C reduces the strength of the shell by 30%, which leads to a reduction in the cost of hulling to 20%. In addition, a less durable shell structure increases the service life of hulling equipment. Lowering the shell temperature below -40°C does not lead to a significant reduction in the cost of hulling and reaching such temperatures entails additional costs [46].

4. CONCLUSION

In this research, lower temperatures of hazelnut shell made it transfer from the mixed fracture to the brittle one in the temperature range of -40...-80°C.

When the temperature fell down to -40℃, the strength of the shell decreased only by 5-8%. When the temperature was between -40℃ and -80℃, the tensile strength decreased by 30-35%, regardless of the size of the nuts. When the shell temperature was reduced to -190℃, the tensile strength was minimal. However, such low temperatures are difficult to achieve and make the cracking economically unfeasible. At shell temperatures below -40℃, the destruction process yielded the smallest amount of fine fraction, and the kernels were maximally intact.

Therefore, hazelnut cracking reached its maximal economic effect at the shell temperature of -40℃. The results can be used to develop new methods and technologies for industrial hazelnut cracking. The obtained -tensile strength values may be used to design new nut-cracking equipment.

Currently, there is no research on the use of low temperatures to improve the efficiency of nut and seed hulling. However, the study of the destruction of materials at low temperatures is a promising direction, as it allows designing new highly efficient hulling equipment. In addition, a decrease in the shell's strength allows increasing the service life of the working parts of the machines, which also directly affects economic efficiency.

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