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Studies on deformation characteristics of albumen belkozin membranes using hysteresis loops technique

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1. Introduction

Packaging materials, which directly contact the food products must possess chemical resistivity, have certain physical, chemical, mechanical and technological properties, meet hygiene requirements and assure high automation level of the packaging process [1-5].

It is quite common that smoked, boiled and liver sausages, also curd, diet curd, curd for children, sour-cream, ice-cream mass and similar consistence products are being packed into round bar-shaped packs produced from the sleeve filled-in with the product. During the filling the sleeve is being portioned and divided into separate round bar-shaped packs by metal clips prior to separating from the sleeve by cutting [5]. The sleeve itself can be made of protein belkozin, polymer povidene, polyethylene and other materials, which meet hygiene, technological and technical requirements and are suitable for the specific product type [2-4].

The protein belkozin casings are used quite often for filling of boiled and smoked sausage meat. The main part of protein film is a protein collagen, which has fibred structure with hard enough separate fibers. These fibers when twisted make up the sieve of quite high mechanical strength. Protein casings during the sausage manufacture are affected by high temperature, pressure and other factors, which obviously have influence on their properties. These factors must be taken into account when choosing the optimal operation parameters. The properties of casings are very much dependant on soaking medium and the soaking duration, therefore these parameters should be set very carefully in order to produce an elastic and nonbreakable casing.

Relaxation tests at load levels below ultimate tensile strength can provide information about deformation properties of the protein belkozin casings used in production of cooked and smoked sausages. Deformation properties are very important especially in case of automatic filling the casings with minced meat where the casings are exposed to several expansion cycles performed at high speed. As a result the casings brake quite often because of limited ability to withstand multicycle loads thus causing various problems related to stability of production process, productivity, etc.

The aim of this study is to determine experimentally deformation properties of casing material at multiple load-unload stress performed at constant speed in order to simulate real working conditions of the casing during the automatic sausage production. Recorded stress-strain curves of the casing material appear in the shape of hysteresis loops and represent the performance of protein belkozin casings during the automatic filling it with the sausage mass. The results presented in this article can be considered as an extension of previous research [1-3].

2. Experimental research methodology

Mechanical properties of belkozin protein film coatings depend on many factors: sample cutting direction, film type and diameter, plasticizing media and others. In this paper we have limited the research, focusing mainly on general properties and their dependence on basic film parameters: type, sample cutting direction and the shell diameter. Mechanical properties of belkozin were investigated using 65 mm film sleeve, type OP. Examination was carried out on longitudinally and transversally cut specimen.

Specimens were cut by using special equipment to ensure that their edges are perfectly smooth. Specimen width was 10 mm and working length – 100 mm.

Prior to tests the samples have passed 48 h conditioning in the atmosphere at normal humidity $w = 65 \pm 2\%$ and temperature $T = 293 \pm 2$ K.

Similarly to [1] during tests the load was applied at a constant 30 mm/min speed until the set load value is reached. It is considered that the load value applied to a specimen is the one, from which starts the unloading. After the application of 2-6 cyclic load cycles, the load has been increased up to the tensile strength. During the tests loading duration was set to be 120 s, unloading – 360 s. Loading force has being increased from 10 N to 40 N by increments.

Film deformation research has been carried out by using universal relaxograph, a special device UM-131 used to electronically measure mechanical parameters also a linear electronic recorder EZ-11.

3. Study of albumen belkozin membrane deformation dynamics by using hysteresis loops

Some researchers claim [6 - 8] that hysteresis stress-strain loops can be both informative and helpful when investigating complex deformation processes of the materials. By registering strain-stress curves caused by the applied load during its increase and deduction at constant speed a number of important physical and mechanical parameters can be obtained: plasticity of the material, its hardening phenomenon, reverse deformation dynamics, etc. Limited stretch of the material is being performed to a certain deformation level below.

During the first stage of research aimed at identifying deformation parameters similar to those occurring during the industrial exploitation, the cyclic load was set within the 75 - 80% of the tensile strength. Each specimen was subjected to a 3 cycle load test with the above load applied, which was afterwards followed by the load to cause fracture. Typically such test produces loading-unloading curve shown in Fig. 1.

An experiment confirmed the earlier obtained belkozin deformation characteristics [1]:

a) during each load cycle belkozin becomes more stiff, which is reflected by an increasing angle α.

b) each load cycle increases an offset strain.

In addition is has been established that a specimen becomes more strong after it has been affected by cyclic load. The application of 3 loading-unloading cycles with the 75% load of ultimate tensile strength (UTS) has led to an increase of UTS value from 54 N to 58 N, or by 7,4%.

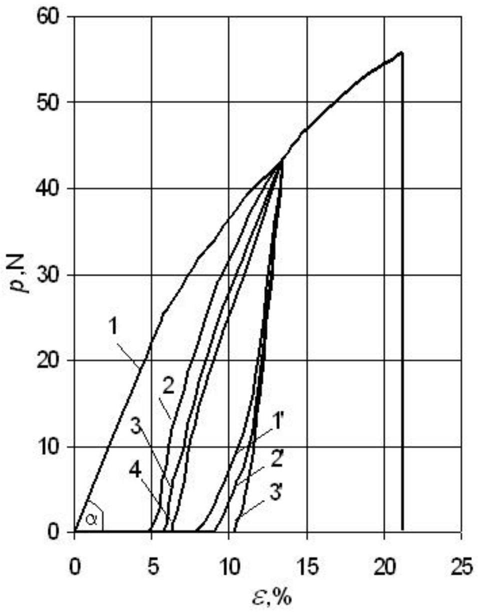


Fig. 1 Hysteresis loop of belkozin film specimen. Specimen cutting direction - transversal. Loading cycles – *1-4*. Unloading cycles - *1'-3'*

Film strengthening phenomenon was observed also during the experiments where variable number of cyclic loads and variable load values have been applied. Please see the test results in Figs. 2 and 3.

It can be seen that in the range from 1 to 5 load cycles the strength of the film is increasing. Further increase of the number of cycles is not followed by the increase in film strength, contrary even some decrease can be observed, especially when higher loads are applied. Supposedly, it happens because the material properties are subject to 2 parallel processes within the material structure, which follow the cyclic load: a) initially observed increasing orientation of the belkozin molecules after the 4-th cycle becomes less displayed; b) material fatigue, which becomes visible with the increase in number of load cycles.

Strengthening process of the film is also subject to the value of cyclic load. Maximum strengthening effect was achieved at the load range from 58 to 62% of the UTS. Approximately 10 - 11% increase in film strength was registered in specimen exposed to 4-5 cyclic loads at 58 - 62% of UTS performed at constant speed. This combination of parameters seems to be optimal for this type of film.

Strain at fracture similarly to the film strength is also dependant on a number of cyclic loads as well as the load value. Curves of the graphs in Figs. 2 and 3 confirm that cyclic loading up to 4-5 times result in increase of offset strain at fracture, while further increase of load number causes adverse effect. Nevertheless, in all the cases a specimen not exposed to cyclic load have produced lower strain at fracture values compared to those exposed to cyclic load. Max observed difference was 15 - 20%.

4. Changes in belkozin structure at stretch

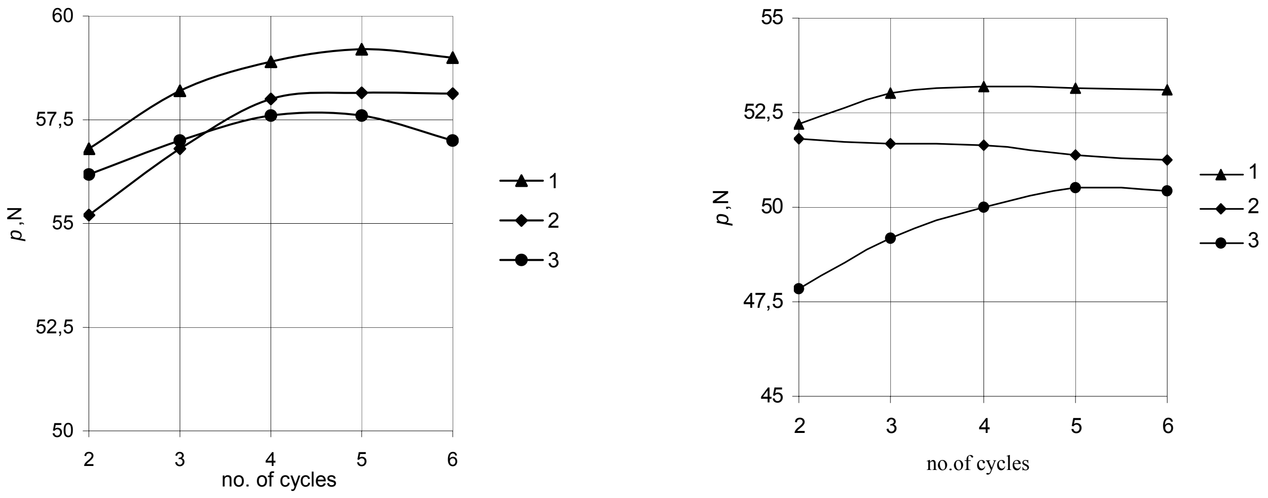
A number of factors should be taken into account when analyzing mechanical properties of belkozin: collagen fiber structure and orientation, interaction between structural elements, influence of inter-fiber filler material on the properties of structural elements and their changes.

Numerous researchers underline close relationship between collagen properties (e.g. strength, ductility, etc.) and the material structure [7 - 10]. Belkozin is a fibrous material with collagen fibers oriented with a certain angle against its longitudinal axis. As a result the fibers inside the longitudinally and transversally cut specimen also appear to be oriented with a certain angle towards the stretch load axis. Belkozin's fiber structure has similarity with mesh-work and its' fiber orientation generally is quite complex. Two major types of bonds occur between the structure elements: interlace of elements and friction bonds.

Some indirect information about the structure of the material being tested and the existing inside links can be obtained from hysteresis loops and their shape. In general the shape of hysteresis loop can be either convex, concave or linear. Hysteresis loop shape of belkozin specimen at stretch presented in Fig.1 suggests that unlikely there do exist any adhesive bonds inside the material structure.

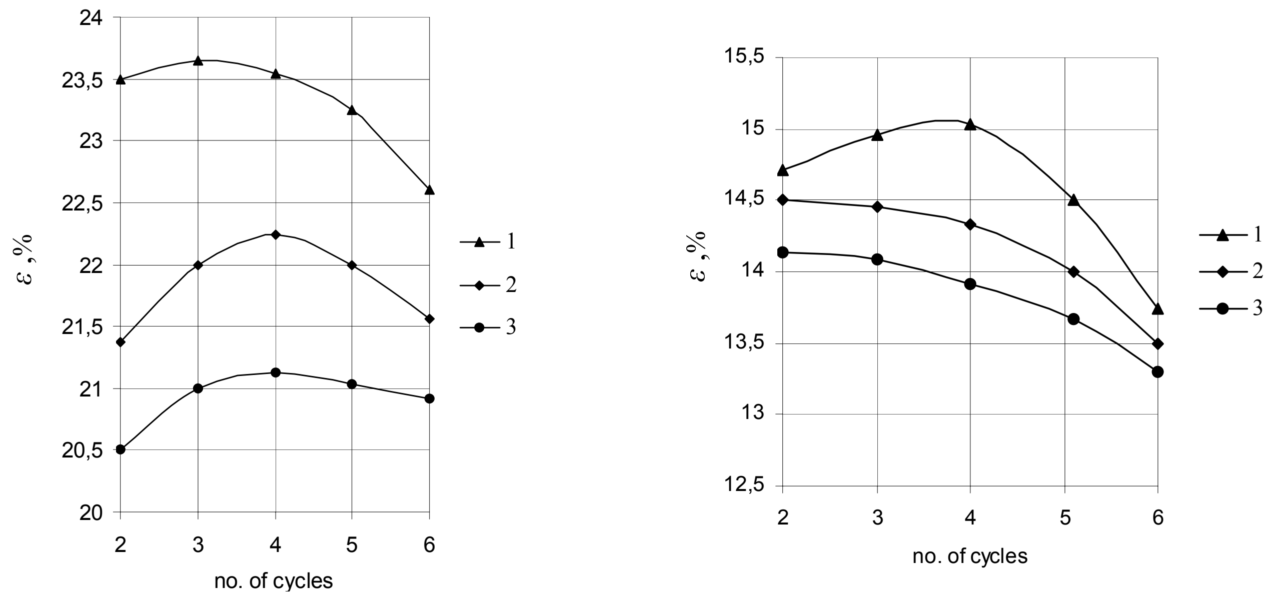
This might be one of the reasons why stiffness and strength properties of specimen are increasing as a result of exposure to cyclic load. Another reason could also be additional bonds between the fibers as described by Mikhailov A.N. [11]. According to him the collagen being a soft capillaries based hydrophilic sorbent tends to loose water as a result of mechanical cyclic loads. Loss of water from capillaries makes the structure drier with more bonds between the fibers, which otherwise would be interlinked via water molecules and virtually would not be active.

Changes of instantaneous offset strain, which appear inside the belkozin structure, can be explained through the loss of partial fiber bonds caused by the applied tensile load. As noted by Pakshver A.B. [7] this has some similarity with the processes in textile materials. Still, the role of collagen fibers and their properties should not be excluded and diminished. Research carried out using different types of collagen fibers has demonstrated the existence of instant offset strain. It's very likely that under the influence of conditional-instantaneous stretch stress of specimen the irreversible structural changes of the fibers is followed by the deformation of collagen fibers themselves.



a b

Fig. 2 Dependence of breaking strength on the load value and a number of load cycles. Load value: *1* - 20 N; *2* – 40 N; *3* - 10 N. a) longitudinal direction, b) transversal direction



a b

Fig. 3 Dependence of strain at fracture on the value of load and a number of load cycles. Load value: *1* – 10 N; *2* – 20 N; *3* – 40 N. a) longitudinal direction, b) transversal direction

5. Conclusions

1. Research of belkozin deformation properties at cyclic loading-unloading, performed at constant speed has been carried out. The registered hysteresis stress-strain loops indicate about the increasing strength of belkozin structure as a result of exposure to cyclic stretch loads. Breaking strength and strain at fracture parameters have been investigated and their dependence on number of load cycles and load value established. At optimal load value, equal to 58 - 62% of ultimate tensile strength and 4 stretch load cycles a maximum of 10 - 11% increase in braking strength and 15 - 20% increase of strain at fracture has been achieved.

2. Experiments have demonstrated that deformation properties of belkozin are subject to film orientation and are different in longitudinal and transversal axis. Belkozin features nonpersistent offset strain, which is dependant on cyclic load, where maximum reduction is being registered during the first load cycle with further declining reduction related to following cycles. Exposure to multiple loads causes permanent increase in film stiffness and the related reduction of ductility with every new load cycle applied.

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BALTYMINĖS BELKOZINO PLĖVELĖS APVALKALO DEFORMACINIŲ SAVYBIŲ TYRIMAS PANAUDOJANT HISTEREZĖS KILPAS

R e z i u m ė

Pateikti baltyminio belkozino apvalkalo deformacinių savybių tyrimai sudarant histerezės kilpų grafikus. Nustatytas belkozino apvalkalo plastiškumo, struktūros sutvirtėjimo efektas, grįžtamosios deformacijos dinamika ir kt. Ištirti trūkio apkrovos ir liekamosios deformacijos pokyčiai trūkio metu priklausomai nuo apkrovos dydžio ir ciklų skaičiaus, taip pat kitos charakteristikos, būtinos tobulinant kimšimo į baltyminės belkozino plėvelės apvalkalą technologijas, automatizuojant gamybą ir parenkant optimalius įrenginių darbo parametrus. Nustatyta, kad belkozinui būdinga kintanti momentinė - liekamoji deformacija. Didžiausia liekamoji deformacija stebima pirmojo apkrovos ciklo metu, o su kiekvienu nauju ciklu jos dydis tolydžio mažėja.

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STUDIES ON DEFORMATION CHARACTERISTICS OF ALBUMEN BELKOZIN MEMBRANES USING HYSTERESIS LOOPS TECHNIQUE

S u m m a r y

The article contains research results of deformation characteristics of belkozin membrane obtained owing to the application of hysteresis loops technique. A number of important parameters for automated production have been established, e.g. plasticity properties, film strengthening phenomenon at cyclic load, reverse deformation dynamics, etc. It was found that belkozin features non-persistent offset strain dependant on cyclic load. Offset strain produces its highest value during the first loading cycle and is declining with every new cycle. The results can be used in setting optimal parameters of automated sausage production.

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