

TDK THESIS

Synthesis and characterization of gelatin, and crosslinked gelatin aerogels



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1 Introduction

Over the last years, aerogels have gained significant attention due to their unique and remarkable properties. Consequently, their introduction to science and industry was just a matter of time. Advances in this field are in continuous development with new types and properties being studied.

Gelatin is a biopolymer which is prepared by thermal denaturalization of collagen, which consists of a large number of glycine, proline, and 4-hydroxy proline residues. It is commonly used as natural macromolecule in the biomedical field due to its excellent biocompatibility, biodegradability, and no immunogenicity. Moreover, is not only a valuable nutrient, but it also promotes the full usage of animals that are primarily raised for their meat — contributing to a zero-waste food economy.

The amino acid chains of gelatin can undergo a crosslinking reaction with aldehydes. Following, gelling properties of gelatin can be altered, so new physical properties (durability, thermal stability, insolubility in water, etc.) and chemical reactivity modifications can be observed.

This research aims to characterize newly synthesized pure high gelatin content aerogels, and the crosslinked version of the gelatin aerogels with glutaraldehyde (GTA). The cross-linking process was achieved by the interaction of the gelatin gel with the crosslinker (GTA) and using a subsequent supercritical CO₂ drying process. Three different aerogels with the following composition will be studied: 30 wt.% gelatin/water (RM01); 20 wt.% gelatin/water (RM04); and 20 wt.% gelatin/water crosslinked with 2.5 wt. % GTA (RM06).

In this research the focus is the characterization of newly synthesized advanced materials by the conventional characterization techniques (SEM, N₂-porosimetry, IR) as well as compressive strength tests. Based on the results the next step is further analysis for specific applications such as: thermal insulation, promising applications in filtration (selective adsorption of Hg, Pt, Pd), catalysis, and medicine (drug delivery, wound healing and tissue engineering).

2 Literature review

2.1 Development of aerogels

Samuel S. Kistler first carried out aerogel synthesis in 1931. He is considered the father of aerogels producing many different types of aerogels: transparent silica aerogels, alumina aerogels, tungsten oxide aerogels, iron oxide aerogels, and tin oxide aerogels [1]. Aerogels were commercialized in the 1940s by Monsanto Corporation, as powdered silica aerogel called “Santocel” used as a thickening agent. However, due to high competition on the market and other cheaper options, the company stopped producing them in the early 1970’s.

Kistler’s wet silica gels were prepared with the condensation of sodium silicate (water glass). However, in these reactions, salts within the gel were formed, and to remove them numerous washing steps were necessary [2]. In the 1970’s a new method was elaborated by Teichner’s group to prepare optically transparent monoliths using tetra alkoxysilanes ($\text{Si}(\text{OR})_4$) as the silica source. The key to this process was to use alcohol (e.g., methanol or ethanol), so the tedious water to alcohol solvent exchange was eliminated [3].

At the beginning of the 1980s, researchers realized that silica aerogels would be ideal media for the production and detection of radiation, specifically Cherenkov radiation. In this experiment, large transparent tiles of silica aerogel are required. By the TMOS method, two large detectors were fabricated (TASSO detector at the Deutsches Elektronen Synchrotron (DESY) in Hamburg, Germany, and CERN at the University of Lund in Sweden) [4].

In the same decade (1980’s), the alkoxide sol-gel process was made less toxic by using a safer alkoxide compound, and the supercritical drying technique was replaced by using supercritical carbon dioxide, because methanol, which was used previously is highly explosive.

In the 1990s, researchers started to be familiar with aerogels and with their unique properties, mainly the NASA started to focus on aerogels. Following years of fine tuning the synthesis, new methods were developed to speed up or even eliminate supercritical drying and use new materials. In 1991, Dr. Tom Tillotson at Lawrence Livermore National Laboratory synthesized ultralow density silica aerogels, which was a Guinness World Record for the lowest density solid (two-step sol-gel process). In 1997, NASA used aerogels to protect the Sojourner rover electronics in exploring the Red Planet in the Mars Pathfinder mission.

The usage of aerogels as insulators was successful, and the technique was applied for the twin Mars Exploration Rovers Spirit and Opportunity [5].

Aerogels have come a long way since Kistler's days, and endless possible applications of aerogel materials make them essential in the scientific field.

2.2 General characterization

Aerogels are unique solid materials; being highly porous and light, they consist of an open-cell network. Their main characteristics are high specific surface area ($500\text{--}1200\text{ m}^2\text{ g}^{-1}$), high porosity (80–99.8%), low density ($\sim 0.003\text{--}0.5\text{ g cm}^{-3}$), low thermal conductivity ($0.005\text{--}0.1\text{ W/mK}$), ultra-low dielectric constant ($k = 1.0\text{--}2.0$) and low refraction index (~ 1.05) [6-7]. The most common synthetic method for producing aerogels is the sol-gel process, especially with metal oxides. Metal oxides have small particle sizes, and varied morphologies [8-9]. The procedure consists of transitioning a system from a liquid "sol" into a solid "gel" phase. The sol-gel process involves the following steps: forming a solution, gelation, aging, drying, and densification.

2.3 Advances in the biopolymer aerogel synthesis

Biopolymer aerogel field is a growing branch which is gaining scientific interest due to its superior properties over the traditional synthetic polymers. One of the main reasons is their highly dense surface functionality: presence of amino groups, carboxyl groups, etc. They can be tuned and selectively functionalized depending on the further application area [10]. The most important strategies for biopolymer aerogels were summarized in Figure 1.

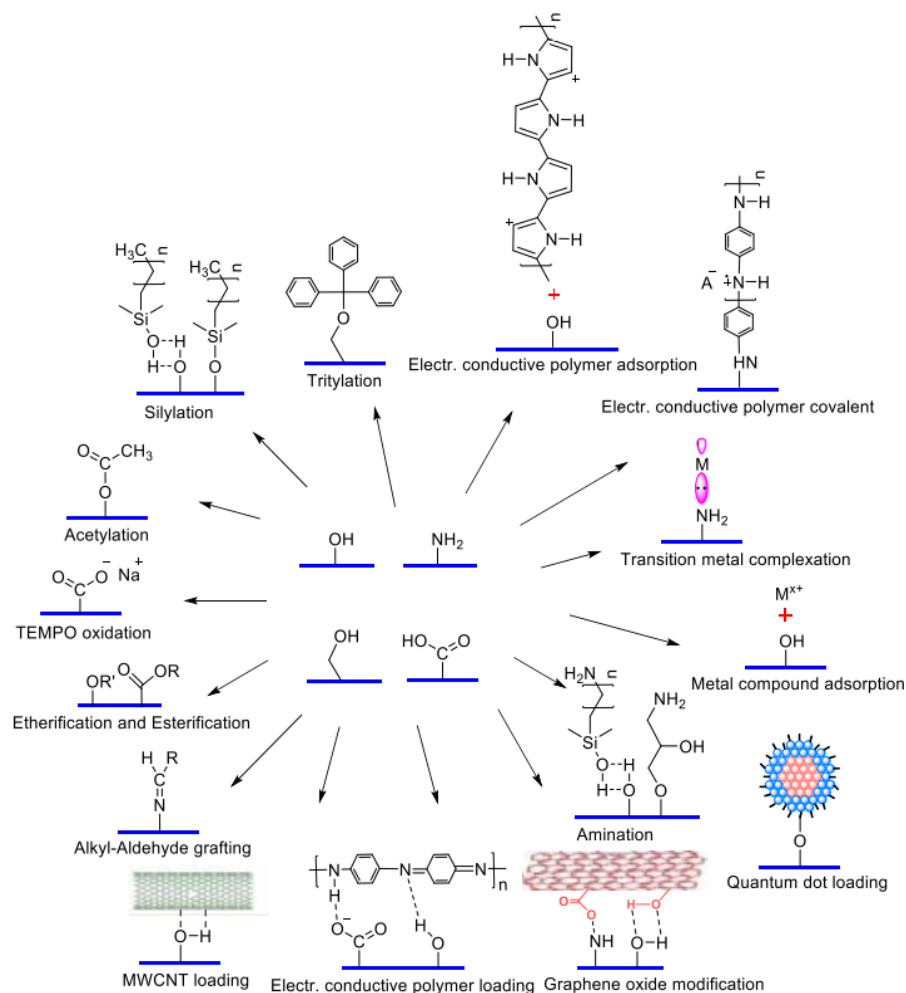


Figure 1. Functionalizing strategies for biopolymer aerogels [10].

Moreover, the non-toxicity and biocompatibility of these materials allows their safe usage in food and pharmaceutical industry. For example, galactomannan aerogels as well as tamarind seed galactoxyloglucan aerogels are promising alternatives as materials for food or food packaging applications. Also, starch aerogels loaded with trans-2-hexenal were synthesized in order to be used as evaporative anti-fungal agent for food protection applications.

In the biomedical field the drug transport application is mostly studied. Research done by Mehling et al. presents the drug loading and release from starch and alginate aerogels [11]. Used for loading paracetamol and ibuprofen, they obtained promising results. First physical properties of the aerogel carriers demonstrated faster release from higher porosity materials as well as the type of biopolymer used, indicated the possibility to engineer selective aerogel release vehicles.

2.4 Gelatin overview

Gelatin consists of a collection of peptides and proteins obtained by partial hydrolysis of collagen extracted from the skin, bones, and connective tissues of animals (cattle, chicken, pigs, and fish). It is made out of a large number of glycine, proline, and 4-hydroxy proline residues (Fig.2).

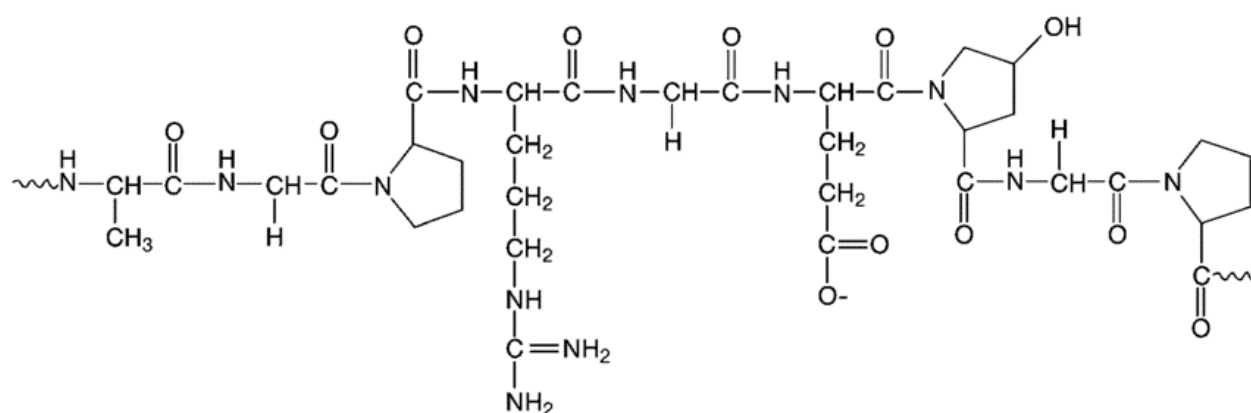


Figure 2. Representative figure of the peptide sequence of gelatin

The FT-IR spectra of gelatin (Fig.3), shows the characteristic functional groups present in the biomolecule as well as its fingerprint which can be further used for comparison purposes [12].

There are four major peak regions, with the following wavenumbers at 3270-2870 cm⁻¹, 1626 cm⁻¹, 1560-1335 cm⁻¹ and 1240-495 cm⁻¹ which correspond to Amide A, Amide I, Amide II, and Amide III regions.

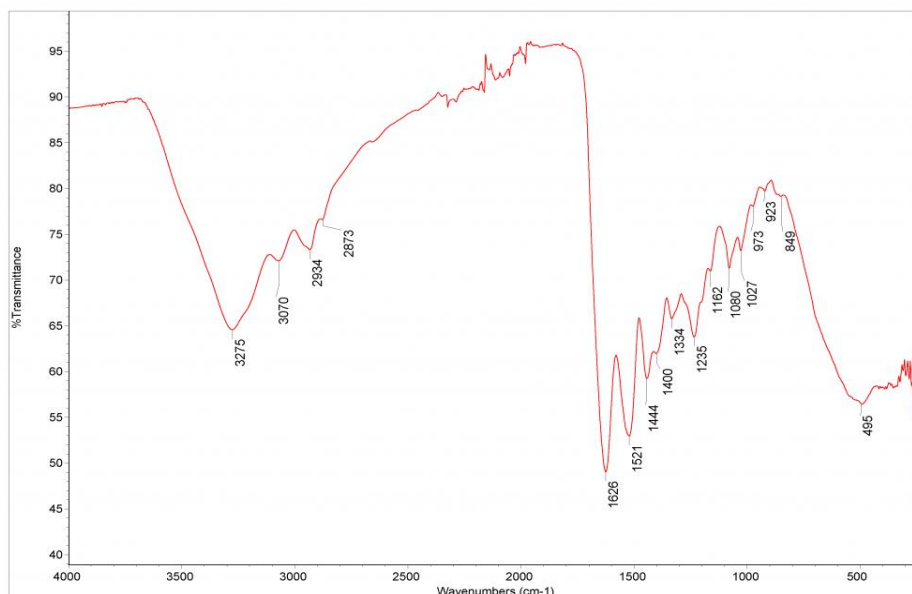


Figure 3. IR-spectra of gelatin [11]

The solid gelatin is soluble in polar solvents such as: hot water, glycerol, and acetic acid, but it is insoluble in organic solvents like alcohol. Commercially available gelatin has a gel strength of around 90 to 300 grams Bloom (by the Bloom test of gel strength). Similarly, to other proteins, its properties are highly influenced by the pH, temperature, ionic strength, additional additives, and the partner crosslinker features.

2.5 Characterization techniques

2.5.1 Morphology of aerogels

Scanning electron microscopy (SEM) is a highly useful technique for imaging the nanostructure of aerogels. Widely used for studying advanced materials, it shows a visual representation which are extremely useful. Among the benefits is the simple procedure of the measurement, and the availability of the instrument. Information on nanometer scale can be extracted from these images such as particles distribution, presence of clusters of particles or interconnected particles, fibrils, and networks of fibrils. The working principle is the following: a sample is scanned with high-energy electron beam. These electrons interact with atoms in the sample and produce various signals that contain information about the surface topography and composition of the sample. Next,

the electron beam is scanned in a raster scan pattern, and the position of the beam is combined with the intensity of the detected signal to produce an image which characterizes our materials.

2.5.2 Porosity measurements

Aerogels are porous materials which are characterized by porosity, the ratio of the pore volume to the volume occupied by the particles or fibrils. Nitrogen adsorption-desorption porosimetry is an important technique which gives information about specific surface areas, pore size distributions, and total pore volumes.

The determination of the surface area is achieved using the multipoint BET method. At the basis we have the BET isotherm types which is a model that aims to explain the physical adsorption of gas molecules on a solid surface. BET is a multilayer adsorption in which it is assumed that initially adsorbed layer acts as a surface and adsorption processes also take place in higher layers [13]. Following we have the relationship between the amount of gas adsorbed v and the relative gas pressure p/p_0 , where p_0 is the saturation pressure at which all pores are filled with adsorbent (Eq 1) :

$$\frac{\frac{p}{p_0}}{v \left(1 - \frac{p}{p_0}\right)} = \frac{1}{c \cdot v_m} + \frac{c}{c \cdot v_m} * \frac{p}{p_0} \quad (1)$$

After the measurement the data is collected and displayed as a plot of the amount of gas adsorbed as a function of the relative pressure. Different types of adsorption isotherms are presented in the following figure (Fig.4).

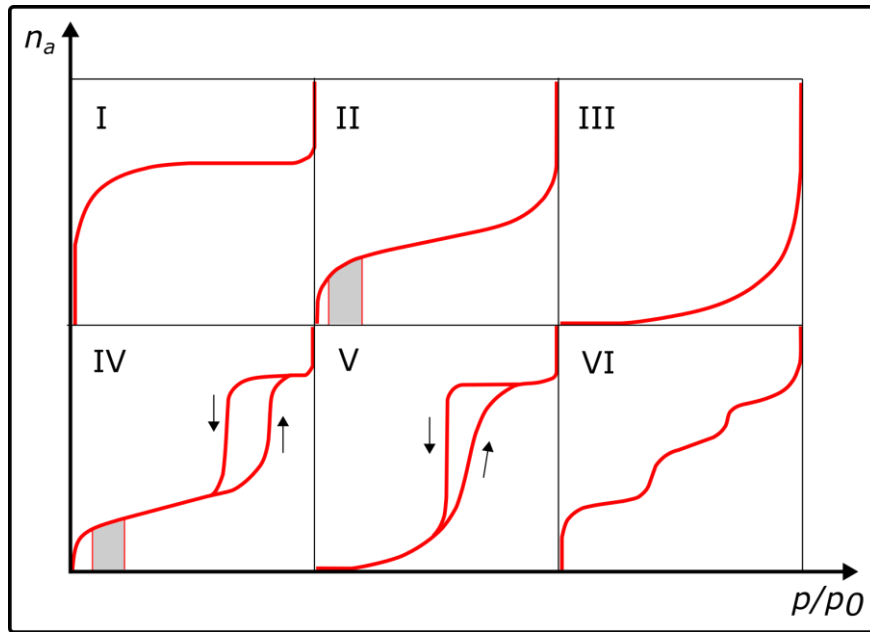


Figure 4. Isotherm types in porous materials [12]

2.5.3 Mechanical strength measurements

The compression test is a technique used to determine the mechanical strength of aerogels by homogeneous uniaxial loads from recorded stress–strain curve. A sample of cylindrical shape of diameter D with height h is placed between the fixed between two parallel plates.

The compression is increased slowly as the sample is charged with a uniaxial load. Then, the corresponding force F is measured while the compression velocity v is kept constant.

After the measurement, compression stress versus strain curve is recorded from which we can determine the Young's modulus.

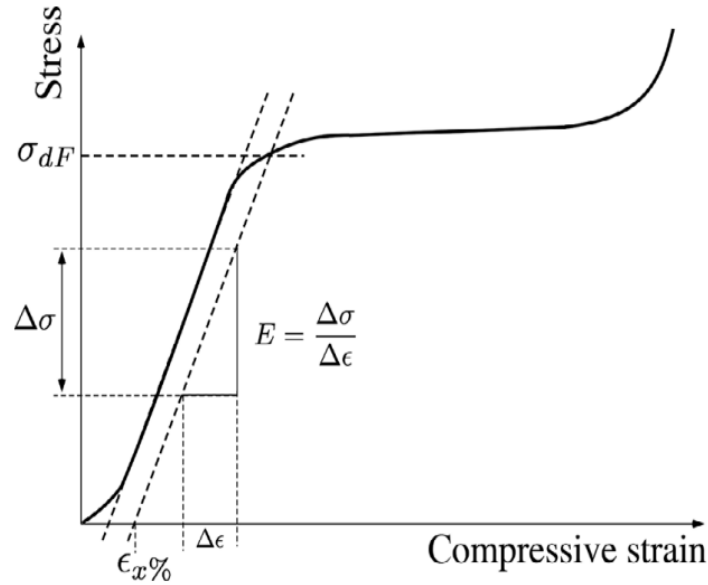


Figure 5. Schematic compression stress versus strain curve of a porous body [14]

Young's modulus is the slope of the linear stress–strain curves at small strains, defined or calculated according to the sketch in Fig.5.

While characterizing aerogels, which are highly porous materials, no standards for mechanical strength measurements are defined. Moreover, in practice, the ultimate strength of a material in compression is not given by the maximum load read off from the curve since it doesn't have physical meaning. The actual strength of an aerogel material is always much smaller than Young's or shear modulus. In other hand these values can be a good approximation when taking the Young's modulus value approx. $E/10$ and to compare aerogels of same type among each other [14].

3 Experimental sections

3.1 Materials and Solutions

The gelatin used was purchased from Dr. Oetker in form of Gelatin Sheets with the following properties: type A gelatin, 150 kDa of 240 Bloom Gold Extra Quality made of pork. The constant quality control and high purity makes it a suitable source of gelatin for this research. Glutaraldehyde (GTA) is from Sigma Aldrich. The aqueous solutions were prepared with ultrafiltered, double-deionized water (Elga PureLab classic system). The organic solvent, methanol

of HPLC grade was also purchased from Sigma Aldrich. For the drying step pure 99.5+ % CO₂ (Linde) was used.

3.2 Preparation of pure gelatin (30 wt.% and 20 wt.%) alcogels

At first, the procedure was challenging since the biopolymer is very sensitive to the following parameters: stirring rate, temperature, shape of broken gelatin sheets and others. The recipe was elaborated meticulously across several concentrations of gelatin being analyzed. Aerogels of varying gelatin content were synthesized by the sol–gel technique. First the gelatin sheets were broken into little pieces. Following the respective amounts (summarized in Table 1.) were measured in a 50ml beaker containing a 15 mm magnetic stirring bar.

Table 1 Gelatin aerogels content in synthesized samples

Code:	Gelatin amount (g)	Water (ml)	Gelatin content (V/V %)
RM01	6.0	20	30
RM02	6.0	20	30
RM03	12.6	20	63
RM04	4.0	20	20

The gelatin was dissolved in 20 ml water at 60-70 °C while stirring at speed 50 rpm for 15min, followed by speed 150 rpm for another 10 min. After the solid was fully dissolved, it was left to cool down at room temperature while continuously stirring at speed 300 rpm. After this the step the mixture was poured in 20 ml syringes (the top was cut down). Finally, they were covered with parafilm and let in the fridge overnight to finish the gelation process.

3.3 Preparation of gelatin crosslinked with GTA alcogels

The preparation of 20 V/V % gelatin was followed as mentioned in the previous section. Once the mixture was fully dissolved and cooled down to room temperature, solutions of various GTA concentrations (Table 2.) were added. After that, the mixture was stirred at high speed for 20-45 s

for homogenization. Finally, it was fast poured into the syringes, covered with parafilm, and left in the fridge overnight.

Table 2. *Gelatin-GTA crosslinked aerogels content in synthesized samples*

Code:	Gelatin amount (g)	Water (ml)	GTA solutions	GTA content (V/V %)
RM05	4	20	0.1g in 5 ml H ₂ O	2.0
RM06	4	20	0.1g in 4 ml H ₂ O	2.5
RM07	4	20	0.1g in 3 ml H ₂ O	3.3
RM08	4	20	0.1g in 2 ml H ₂ O	5.0

3.4 Supercritical drying of the aerogels

Once the procedure was elaborated the next step was the determination of the most suitable solvent for the drying process. Three different organic solvents have been tested: acetone, methanol, and ethanol. The latter one, C₂H₅OH, was chosen since it had minimal shrinkage and the shape was almost intact after the 3 steps of solvent exchange. The next procedure, the supercritical drying was done at low temperature to prevent the cracking of the monoliths.

After 24h the alcogels were transferred into cylindrical aluminum molds with holes to exchange the solvent from water to methanol. The first step was pure water, followed by 1:3 methanol/water mixture, 1:1 methanol/water, 3:1 methanol/ water and lastly pure methanol (each step for 24-48h). In order to remove the traces of water from the porous system, a continuous-mode solvent regeneration and extraction unit was used for 3 days with fresh methanol every day (Fig.6).



Figure 6. *Solvent regeneration and extraction unit*

The synthesis of aerogels was achieved by the supercritical drying of the materials with CO₂. First methanol was extracted with liquid CO₂ at 50 bar at room temperature. The extensive solvent exchange ensures the reproducibility of the final aerogels and assures that the materials don't contain any traces of the previously used solvents. This is complemented by aging before supercritical drying to establish the completion of all secondary chemical processes.

The gel was dried with supercritical CO₂ at 99 bar and 40 °C by using the medium-pressure technique [15].

Three types of aerogels with the following codes: RM01- 30 wt.% gelatin; RM01-20 wt.% gelatin and RM06-20 wt.% gelatin crosslinked with 2.5 wt.% glutaraldehyde, were for further characterized in this TDK thesis (Fig.7).



Figure 7. Pictures of freshly synthesized aerogels with their identity codes

3.5 Physicochemical characterization

The morphology of the three aerogels were studied by scanning electron microscopy (SEM). The aerogels were imaged using ThermoFisher Scientific Scios 2 instrument. The aerogels were attached on vacuum-resistant carbon tapes. The measurement parameters were the following: acceleration voltage 1-2 kV, with the resolution 500 nm and 1 μ m , the magnification of 12-120000x. By applying this low acceleration voltage, the charging effects of the aerogels were minimized, so there was no need for sputter coating.

Using N₂-porosimetry the specific surface areas, pore size distributions, and total pore volumes of aerogel samples were measured. The instrument used is Quantachrome Nova 2200e with degassing at 40 °C for 24 h. The software which analyzed the data is NovaWin 11.0 (Quantachrome Instrument,USA). The specific surface area was calculated by using the multipoint BET method (five points on the adsorption curve) and the pore size distribution was calculated from the desorption curves by the BJH method. It assumed cylindrical pore geometry for the calculations.

The infrared spectrum of a sample was recorded by PerkinElmer Spectrum IR-ES instrument. The software used for data analysis is Spectrum IR-ES 10.7.2.1630 (Perkin Elmer). The resolution for the measurement was 2 cm⁻¹ with accumulations of 8 scans.

Mechanical characterization was achieved by the compression test, performed on Instron instrument at room temperature at crosshead speed of 1 mm·min⁻¹. The full-scale load range used was 10 kN for the newly synthesized aerogels. Three parallel monoliths of cylindrical shape, with

13.53-15 mm diameter and 20.99-22.64 mm height, were carefully prepared for this measurement. The samples were measured in the as-prepared states as dry aerogels.

The data was recorded by Instron Series IX Automated Materials Tester v.8.30.00 software. The Young's modulus was determined by the instrument controlling software and then these values were investigated by comparing with the theoretical background of these materials.

4 Results and discussion

4.1 Aerogel Characterization

The advanced materials were successfully synthesized. Once the aerogels were dried, the next obstacle was to find a way to break/cut the monoliths for the upcoming sample preparation in the characterization measurements. This part was physically challenging, since the materials display superior mechanical properties, later confirmed by the compression test results. The aerogels characterized by conventional techniques (SEM, N₂-porosimetry, IR) and mechanical strength measurements to get an overview on the morphology and the chemical structure.

4.1.1 Scanning Electron Microscopy (SEM)

Characteristic SEM images of 35 K and 65 K magnification of pure gelatin and gelatin crosslinked aerogels are presented (Fig.8). Just by analyzing these images we can clearly differentiate between the two types. For the sample RM01 (pure gelatin aerogel) we see a fibrillar structure characteristic for biopolymer aerogels. The cross points between these fibrils are chemical interactions, more specifically they are held together by secondary chemical bonds. On the other hand, RM06 (crosslinked aerogel), exhibits a different type of network and the "typical" bio-fibrils characteristic is less obvious. In this case the structure is more dense and spherical nanopores can be observed. As a result, both the number and size of pores are highly influenced by the gelatin content as well as the crosslinker.

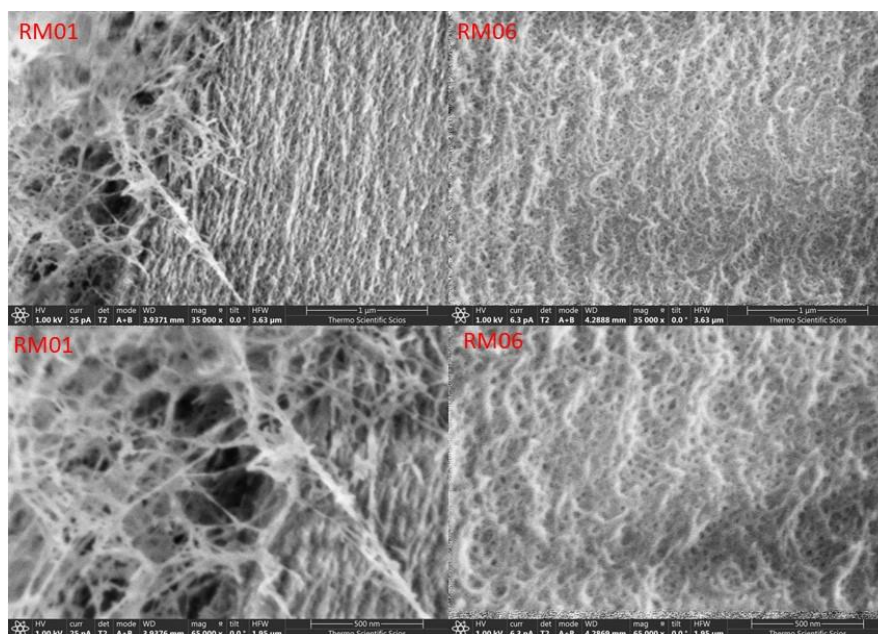


Figure 8. Characteristic SEM images of the RM01 and RM06 samples

4.1.2 N₂ Porosimetry

The characteristic N₂ adsorption-desorption isotherms were recorded for the three synthesized materials with the codes RM01, RM04, RM06 in the Fig.9 and Fig.10

Based on the shape of the isotherms they fit in the type IV (H3) hysteresis given by IUPAC classification. This is characteristic for mesoporous materials with pores in diameters between 2 - 50 nm. Pore size distribution curves are calculated by the BJH method from the desorption isotherms. The results are summarized in the Table 3. for all three types of aerogels.

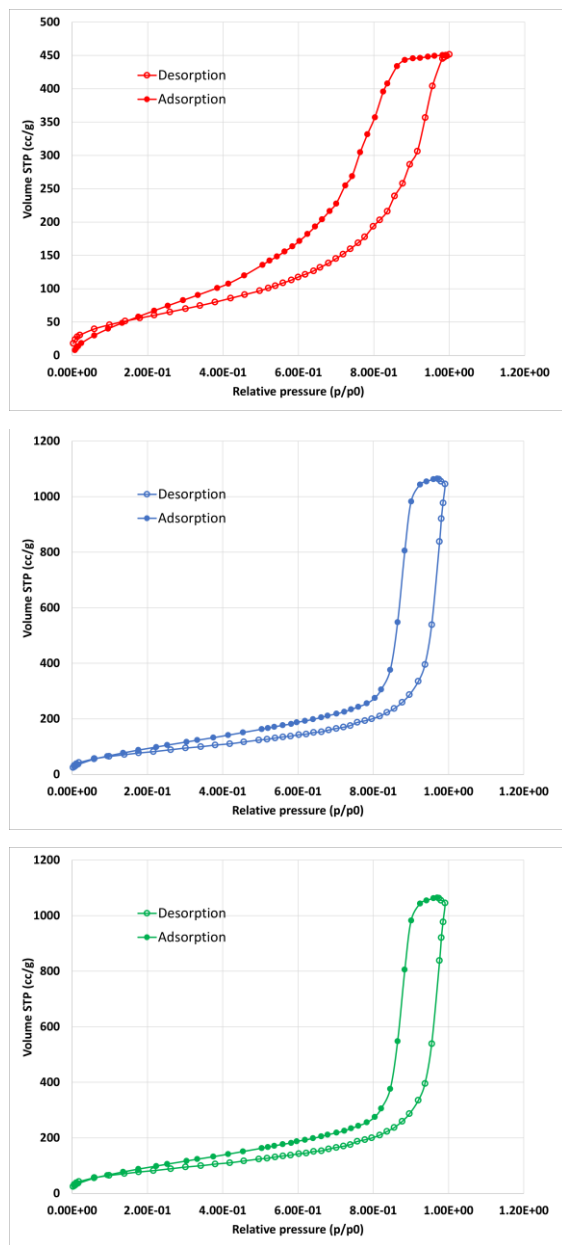


Figure 9. Nitrogen adsorption-desorption isotherms of the three samples (RM01-red, RM04-blue, RM06-green)

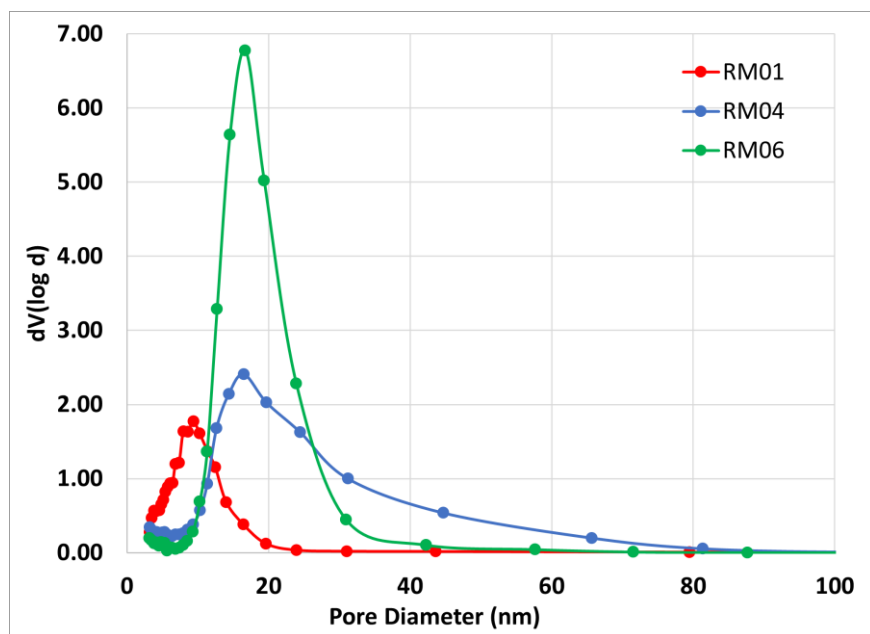


Figure 10. Pore size distribution using the BJH method

Table 3. Structural parameters of the aerogels estimated by BET and BJH methods from the N_2 adsorption-desorption porosimetry data

Parameter	RM01	RM04	RM06	Method
C-constant	33.299	42.031	45.647	BET
Specific surface area (m^2/g)	227.493	256.627	302.506	BET
Average pore size (nm)	7.972	14.417	16.739	BJH
Pore volume (cc/g)	0.745	1.146	1.676	BJH

As it can be seen, the specific surface determined by BET method (S_{BET}) is increasing with higher gelatin content and by adding a crosslinking agent in this case GTA. Moreover, this confirms the presence of higher average pore size upon the addition of glutaraldehyde. Besides the specific surface area, all the parameters are increasing towards the higher gelatin content, and the highest values are in every case at the crosslinked version.

4.1.3 IR spectroscopy

The FT-IR spectrums of the three materials were recorded in Fig.11. The following functional groups can be identified: 3275-3295 cm^{-1} – amide N-H bending; 2900-3000 cm^{-1} C-H stretching; 1590-1690 cm^{-1} N-H stretching; 1406-1438 cm^{-1} C-H bending and 1215-1337 cm^{-1} C-N stretching. Moreover, by comparing the recorded spectra with the reference gelatin one we can see overlap of peaks and similar pattern. However, the glutaraldehyde characteristic peaks at 3429 cm^{-1} O-H stretch of H-bonding, as well as 1564 cm^{-1} for C=O stretch, cannot be seen due to the low intensity of the signals and overlapping effect of higher intensity peaks associated with the gelatin.

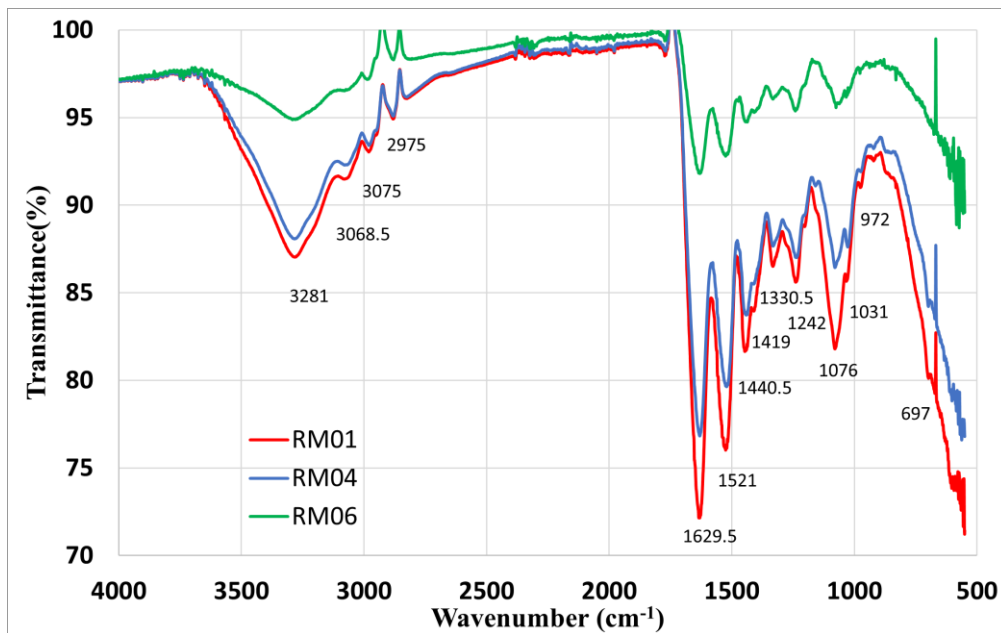


Figure 11. Infrared (FT-IR) spectrum of the RM01 (red color), RM04 (blue color) and RM06 (green color). The major peaks are given in cm^{-1}

4.2 Compression test

The experimental displacement-load curves and the Young's modulus values calculated by the instrument software by the classical considerations are shown in Fig. 12.

Aerogels experience different stages of deformation. The three events are: elastic deformation, compaction and densification regimes.

First is the linear elastic regime which is seen after the initial load. It appears as a linear portion that can be measured and it characterizes the apparent elastic deformation regime: stress and strain

are linearly related. Following, there is an abrupt change of the linear trend. After this region, also called plateau region a third part with a large compressive strain and a smaller increase in stress is observed. This stage ends when the densification of the porous aerogels starts to become significant. Then there is only a small increase in deformation strain but a large increase in stress

Table 4. Mechanical strength parameters of newly synthesized aerogels calculated by Instron Corporation Series IX Automated Materials Testing System 8.30.00

Sample	Gauge length (mm)	Diameter (mm)	Area(mm ²)	AutYoung (MPa)
RM01	20.99	15.00	176.715	243.477
RM04	22.64	13.53	143.776	140.303
RM06	24.37	14.92	174.835	73.695

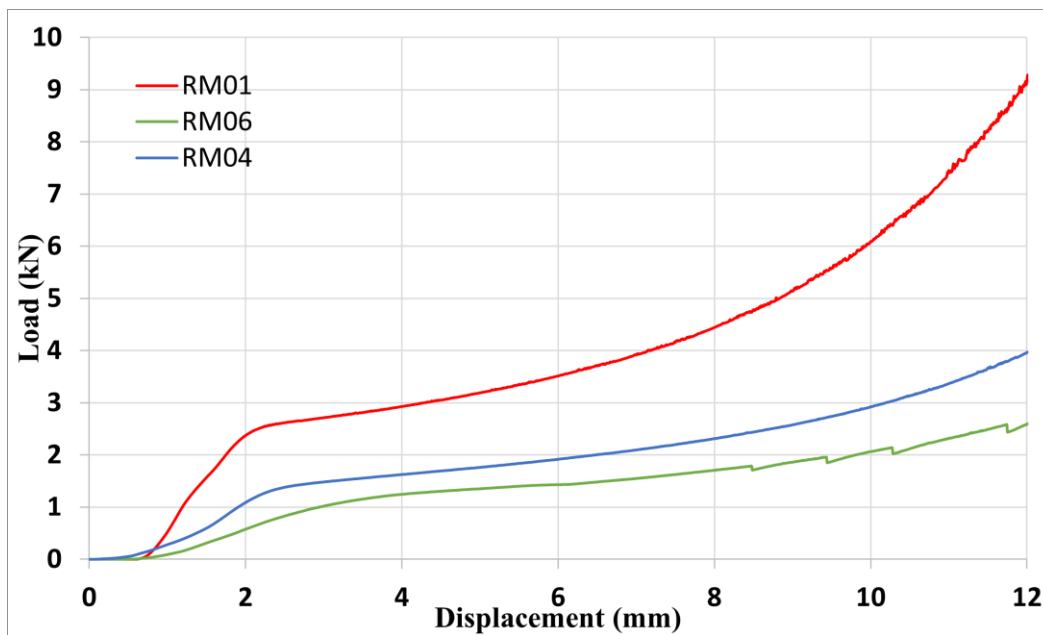


Figure 12. Results of gelatin and GTA-gelatin crosslinked aerogels monoliths compression tests. The plot of load in kN as a function of displacement is shown. The samples parameters are given in Table 4.

Pictures were taken before and after the measurement of the monoliths (Fig.13). As it can be seen there are no cracks on the surface of the aerogels after the compression. The materials show amazing mechanical properties and behave similar to plastics which is an important characteristic for further usage in construction or heat insulator materials.

The measured values show us that the highest Young's modulus is at the lower gelatin content and it is getting lower with the crosslinking. The instrument software is using the maximum point in the load compression curve which leads to values of strength much higher than real Young's modulus, which is unphysical. For this reason, additional mathematical fitting using a standard model is necessary to determine the actual values.

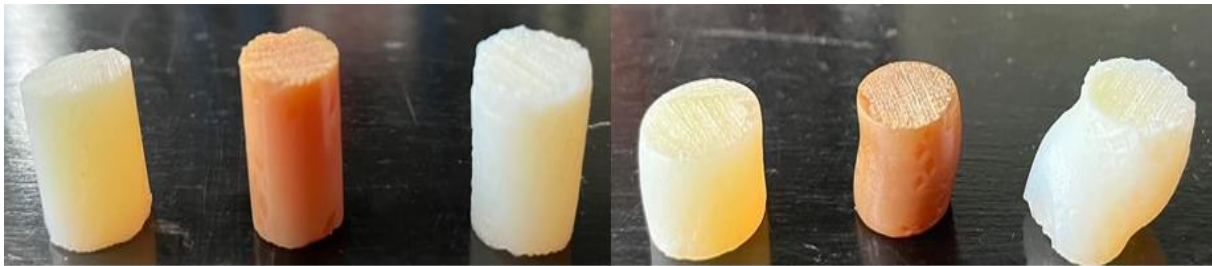


Figure 13. Compression test before and after (1st sample RM01, 2nd sample RM06, and 3rd sample RM04)

5. Summary and Conclusions

In this research the main goal was the synthesis and characterization of new advanced materials from bio-waste, gelatin. These aerogels show outstanding mechanical properties as well as insulating characteristics. Moreover, the crosslinked biopolymer is insoluble in water which can open new possibilities in the usage of these materials in construction.

The SEM pictures illustrate the dense fibrils like structure of the pure gelatin samples and the altered one of the GTA-gelatin crosslinked. This feature has an impact on the strength of the two types of aerogels. Moreover, with increasing gelatin content we can observe a trend in increasing the mechanical properties which give these materials the ability to withstand high stress.

Aerogels used in biomedical studies should be biocompatible and biodegradable. Biological macromolecule-based aerogels are particularly suitable for implants such as membranes, tissue growth scaffolds. As an oral drug delivery system, silica aerogels can be used, since they are biocompatible.

A future prospect is to analyze the innovative aerogels for the following applications: Industry and Construction (Insulation materials), Bioengineering as drug carrier and tissue replacement (biocompatibility and non-immunogenicity), Environmental cleaning (Selectively adsorbing heavy metals: Hg, Pt, Pd). Current studies are under investigation relating to the latter topic which show promising results in the field.

6. Rezumat

În ultimii ani, aerogelurile au câștigat o atenție semnificativă datorită proprietăților lor unice și remarcabile. În consecință, introducerea lor în știință și industrie a fost doar o chestiune de timp. Progresele în acest domeniu sunt în continuă dezvoltare, noi tipuri și proprietăți fiind studiate. Această cercetare își propune să caracterizeze aerogeluri cu conținut ridicat de gelatină pură, novice și versiunea reticulată a aerogelurilor de gelatină cu glutaraldehidă (GTA). Procesul de reticulare a fost realizat prin interacțiunea gelului de gelatină cu agentul de reticulare (GTA) și folosind un proces ulterior de uscare cu CO₂ supercritic. În aceasta lucrare vor fi studiate trei aerogeluri diferite cu următoarea compoziție: 30% în greutate gelatină/apă (RM01); 20% în greutate gelatină/apă (RM04); și 20% în greutate gelatină/apă reticulate cu 2,5% în greutate. % GTA (RM06).

În această cercetare se pune accentul pe caracterizarea materialelor avansate nou sintetizate prin tehnici convenționale de caracterizare (SEM, N₂-porozimetrie, IR), precum și teste de rezistență la compresiune. Acești aerogeluri prezintă proprietăți mecanice remarcabile, precum și caracteristici izolante. În plus, biopolimerul reticulat este insolubil în apă, ceea ce poate deschide noi posibilități în utilizarea acestor materiale în construcții.

Imaginile SEM ilustrează structura fibrelor dense a probelor de gelatină pură și cea modificată a gelatinei GTA reticulate. Această caracteristică are un impact asupra rezistenței celor două tipuri de aerogeluri. Mai mult, odată cu creșterea conținutului de gelatină putem observa o tendință de creștere a proprietăților mecanice care conferă acestor materiale capacitatea de a rezista la stres ridicat.

Aerogelurile utilizate în studiile biomedicale trebuie să fie biocompatibile și biodegradabile. Materialele biologice pe bază de macromolecule sunt potrivite în special pentru implanturi, cum ar fi membrane și schele de creștere a țesuturilor. Ca sistem de administrare orală a medicamentelor, aerogelurile de silice pot fi utilizate, deoarece sunt biocompatibile.

O perspectivă de viitor este analiza aerogelurilor inovatoare pentru următoarele aplicații: Industrie și Construcții (Materiale de izolare), Bioinginerie ca purtător de medicamente și înlocuire a țesuturilor. Pe baza rezultatelor, următorul pas este analiza suplimentară pentru aplicații specifice,

cum ar fi: izolație termică, aplicații promițătoare. în filtrare (adsorbția selectivă a Hg, Pt, Pd), cataliză și medicamente (livrarea de medicamente, vindecarea rănilor și ingineria tisulară).

7. References

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