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Synthesis and Characterization of Hybridfiber from Gelatin Modified by PVACOS Using Coaxial Electrospinning Techniques as an Advanced Medical Textile Material

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Abstract

The synthesis of hybrid fiber based on bovine bone gelatin combined with polyvinyl alcohol-chitosan-oxidized sucrose (PVACOS) has been successfully carried out using the coaxial electrospinning technique. The presence of oxidized sucrose can improve the diameter and the tensile strength of hybrid fibers due to the formation of new covalent bonds. The combination of gelatin with PVACOS material aims to increase the strength of the hybrid fiber so that it has better tensile strength characteristics and improves the diameter of the resulting hybrid fiber. The characterization of the resulting material was tested using FTIR, SEM, EDX, XRD, and TGA. Based on FTIR analysis, there is an increase in absorption intensity in the 2900 cm^{-1} – 3000 cm^{-1} band, which indicates the occurrence of covalent bond interactions so that it can increase the bond strength between materials with the performance of crystalline materials. Apart from that, the morphological structure of the hybrid fibers was also investigated using scanning electron microscopy (SEM), and the resulting fiber diameter for Ge-Ch, Ge-Ch-PVA, Ge-PVACOS 3%, and Ge-PVACOS 5%, respectively, was 0.4049 µm. 0.3735 µm, 0.3388 µm, and 0.3206 µm. The tensile strengths of hybrid fiber for Ge-PVACOS 3% and Ge-PVACOS 5%, respectively, are 39.91935 N/m^2 and 76.12507 N/m^2. Statistical tests show that the concentration of oxidized sucrose has a significant influence on hybrid fiber performance. The significance values for diameter and tensile strength are 0.0486 and 0.0325, respectively. According to this performance, the Ge-PVACOS hybrid fiber is recommended as a material for advanced medical textiles.

Keywords:

Chitosan;
PVA;
Oxidized Sucrose;
Coaxsial Electrospinning.

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1- Introduction

Medical textiles are a significant and vital concern, considering that people need to use them, especially since the COVID-19 pandemic [1]. The need for medical supplies such as mask lining materials, surgical threads, bandages/gauze, hand scoops, and respirator air filters is increasing [2]. An example is a medical thread, which is very important, especially after surgery. Figure 1 shows that more research needs to be conducted on medical textiles. Based on a literature review for 2005–2024 using the keyword medical textiles, the authors found 590 articles. The trend is decreasing, so it is necessary to improvise research in the manufacture of medical textiles. Figure 2 shows the network visualization distribution of medical textile research topics. There is still very little research on medical textiles in the network visualization distribution, especially on characteristics. Characteristics here mean mechanical properties, diameter, and strength.

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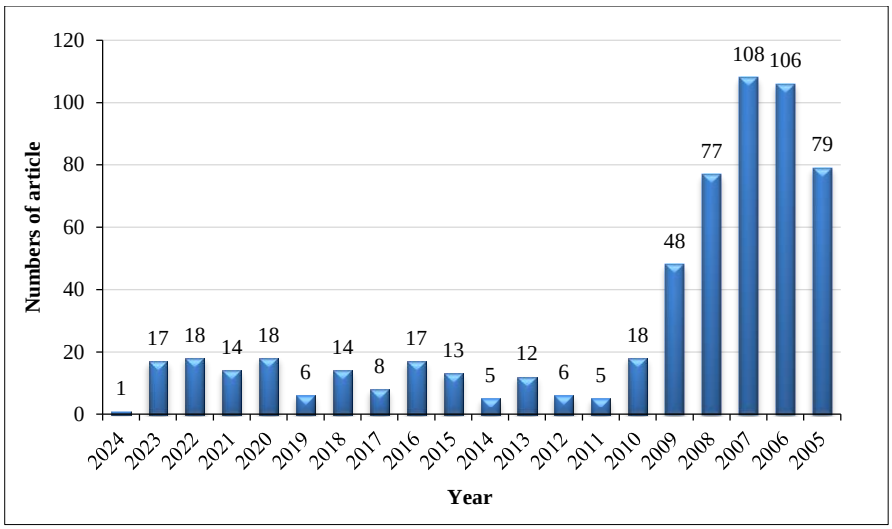


Figure 1. **Distribution of Research on Medical Textiles**

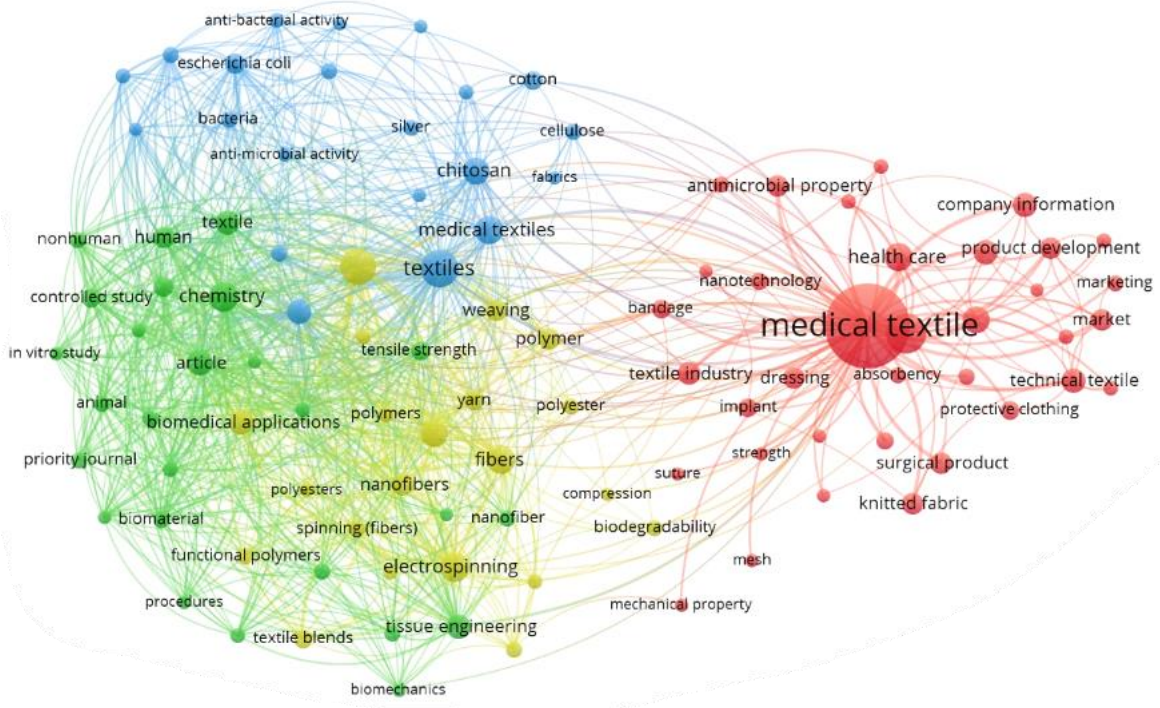


Figure 2. **Network Visualization**

In Indonesia, 94% of the need for medical fiber is still imported from abroad, so innovation is needed to reduce the number of imports of medical thread [2]. Medical textile fibers must meet their characteristic requirements. Medical fibers' characteristics include mechanical properties, diameter, strength, non-toxic, non-allergic response, biocompatibility, biodegradability, good absorbency, accelerated wound healing, and good mechanical properties [3].

Research that has been carried out on materials that can be used to make medical textile fibers includes cow intestine [4], gelatin [5], alginate [6], sericin [7], cyclodextrin [8], triclocan [9], polydioxanone [10], nylon [11], polypropylene [12], and polyester polymer [13]. Among these materials, namely cow intestine, gelatin, and alginate, are sources of renewable materials. Cow intestines have more complex characteristics, so they are not recommended for suturing wounds or soft tissue lacerations. In addition, medical textile fibers from cow intestines partly cause itching and inflammation [14]. Alginate has syneresis properties, namely surface shrinkage due to the evaporation of water content, causing surface irregularities [15]. Gelatin has good absorption properties, plays a role in the blood clotting process, and can promote cell proliferation and attachment [16]. Making gelatin from beef bone was carried out by Fatimah et al. [17], with the operating conditions of soaking in a 5% HCl compound for seven days at a temperature of 70°C. This research resulted in a gelatin viscosity of 3.19 cP. Apart from that, making gelatin from frog bones, tuna bones, and chicken bones with the operating conditions studied includes the soaking time and type of extraction solvent used [18]. Research that uses the same variables includes gelatin from milkfish scales [19], poultry bones [20], camel skin [21], and buffalo skin [22]. The research gap in those studies can be concluded in Figure 3.

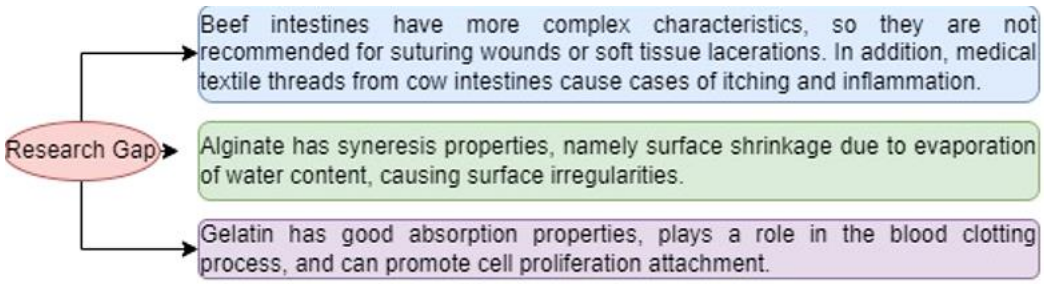


Figure 3. The Research Gap

An alternative that can be used as a raw material for gelatin is cow bone, which is the primary source of material for making medical textile fibers. In cow bones, gelatin compounds can be further converted into material for making medical textile fibers [23]. Gelatin is obtained from the partial hydrolysis of collagen found in skin, muscles, mammal bones, fish bones, and chicken feet' skin. The main properties of gelatin are that it is biodegradable, biocompatible, and non-toxic. This is because gelatin is a natural ingredient that contains high levels of amino acids. The most dominant amino acid content as a parameter for determining gelatin quality is the content of proline, glycine, and hydroxyproline [24]. In addition, gelatin also contains other amino acids, such as glutamic acid, aspartic acid, arginine, proline, hydroxyproline, lysine, isoleucine, methionine, leucine, and valine. To bring out its antimicrobial properties, it is combined with compounds that have depolarizing activity on microbial cell membranes. Compounds that meet these criteria include chitosan [25] and alginate [16]. Zheng et al. [16] explained that chitosan and alginate contain active groups of amine compounds, but chitosan is more recommended because it is cheaper than alginate.

Chitosan is a polysaccharide compound that can increase adsorption properties and is easy to biodegrade. Apart from that, chitosan compounds can also inhibit the growth of microorganisms due to the presence of primary and secondary hydroxyl groups. This causes the peptide chain to become hydrophobic, making it difficult for bacterial membranes to penetrate [26]. A study by Dinh et al. [27] proved that chitosan can inhibit bacterial growth in biocomposites.

Research by Cao et al. [25] suggests that adding additional crosslinkers will increase fiber strength and the mechanical strength of the resulting material. Li et al. (2016) added compounds containing aldehyde or alcohol groups as crosslinkers in the fiber manufacturing process and had the effect of increasing mechanical strength. This is due to the increased strength of the hydrogen bonds formed [26]. Research on making fiber from gelatin with polycaprolactone (PCL) crosslinker has been carried out by several researchers. This research produces biodegradable fiber but has the weakness of being hydrophobic [28]. In some instances, this is acceptable, but in the manufacture of medical textile fibers, this is considered not good because it has a low water absorptivity [29]. Other research that has been carried out includes making gauze fibers from gelatin combined with alginate from seaweed [30], but there has yet to be studied about activity against microorganisms. To increase the tensile strength, it is mixed with chitosan, which allows it to increase the fiber strength [31]. Apart from using chitosan, it can also be done with polyvinyl alcohol (PVA). The PVA agent has the advantage of helping form fibers or fibrils. In PVA, there are hydroxyl groups that will facilitate the formation of covalent bonds. Besides adding PVA, carbohydrate derivatives can also form covalent bonds, helping the fiber formation process. Carbohydrate derivatives that can be used include oxidized sucrose with periodate. Sucrose has an aldehyde group and an alcohol group [19, 32] and is also very eco-friendly [33].

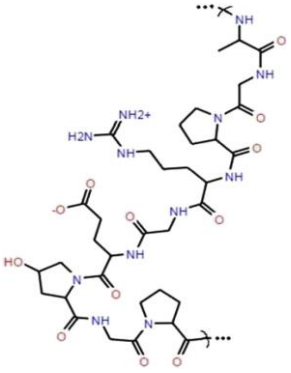
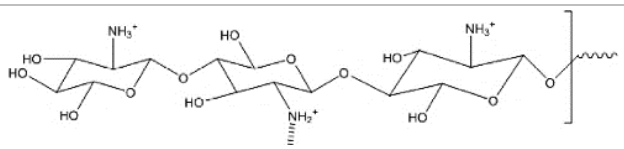
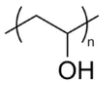
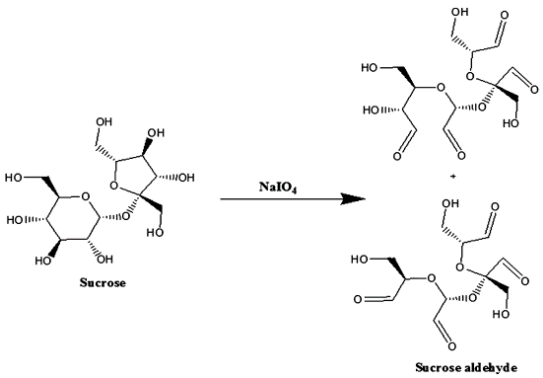
In this research, the combination of gelatin with PVACOS has been done well. Table 1 shows the structural formula of each material. Based on the characteristics and potential of this material, it is necessary to conduct a study to make medical fibers from a mixture of gelatin, chitosan, PVA, and oxidized sucrose. This process can be carried out using an advanced method through a coaxial electrospinning process. Several researchers do wet spinning, but it is less effective in forming fibers [34-38].

Coaxial electrospinning is a technology for making hybrid fiber/yarn with several advantages. The first is that mixed fiber/yarns with diameters up to nanosized are produced, namely less than 100 nm. In the world of textiles, nanosize is the size of fibers/threads with a diameter of less than 100 nm [39]. Second, hybrid fibers are produced, which include a large surface area, a structure with tiny pores, the possibility of forming three-dimensional materials, and a good level of elastic modulus. Third, hybrid fibers are produced with the thickness of the smallest size range, namely 0.04–2 microns. Fourth, the tool is simple and more efficient. Research on synthesizing medical textiles using electrospinning still needs to be done. This can be illustrated in Figure 4, which explains that the synthesis of medical textiles using electrospinning is in the dark-density area and far from the yellow medical textile cluster. More research is needed on using coaxial electrospinning as a medical textile material application [40]. This can be seen in Figure 5, so it is necessary to conduct further studies on the application of coaxial electrospinning.

Coaxial electrospinning is the process of making hybrid fiber by utilizing the influence of an electric field to produce a jet of electrically charged polymer solution or melt. Polymer hybrid fiber threads are formed because, in this process,

the solvent evaporates simultaneously. The principle of the mechanism for developing hybrid fiber by electrospinning is by pushing the polymer solution, which is given a high electric voltage using a syringe pump, so that droplets/drops of solution will form at the end of the spinneret capillary. Grains/drops of polymer solution that have been induced by an electric charge under the influence of an electric field will jump or move towards the electrode with the opposite charge while being accompanied by the process of evaporation of the polymer solvent so that only the polymer fibers are left on the collecting plate [41]. Several factors that can influence the characteristics of the hybrid fibers produced from the electrospinning process include solution concentration, viscosity, surface tension, electrical voltage, and the distance between the spinneret and the collector [39, 42].

Table 1. Material Composition Structural Formula PVACOS

Materials	Structure	References
Gelatin (Ge)		Tyuftin & Kerry (2021) [35]
Chitosan (Ch)		Sathisaran & Balasubramanian (2020) [36]
Polyvinil Alcohol (PVA)		Nasseri et al. (2016) [37]
Oxidized Sucroses (OS)		Jalaja & James (2015) [38]

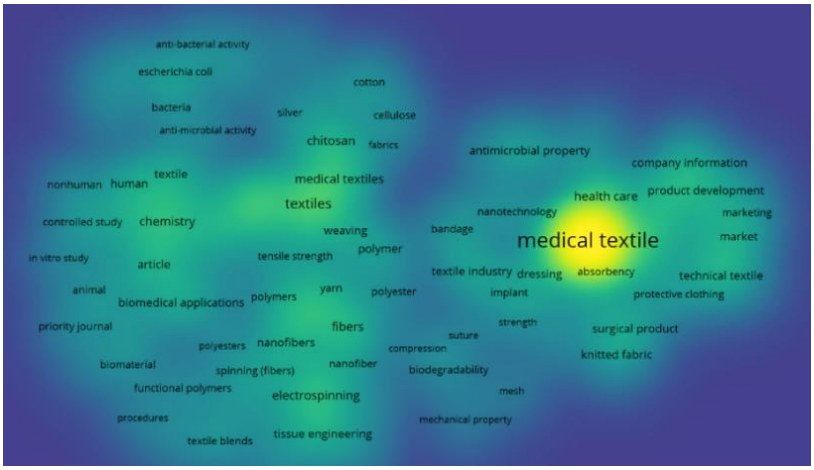


Figure 4. Density Visualization of Medical Textile Research

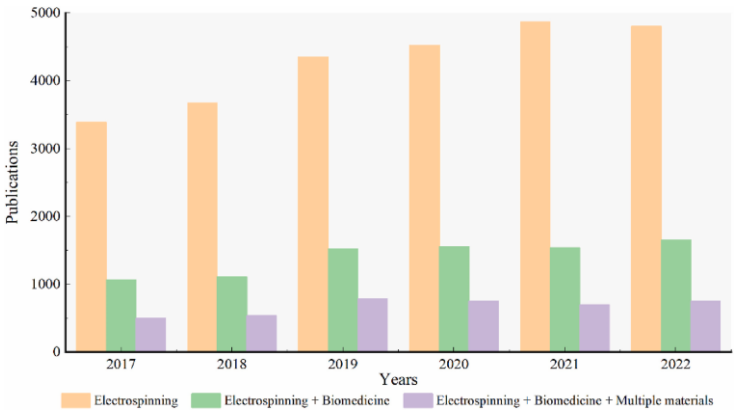


Figure 5. Electrospinning Application [40]

The concentration of the solution is built from the composition of the solution so that it will affect the characteristics of the hybrid fibers produced. The higher the solution concentration, the more molecular interactions may occur. This interaction with the effect of electrical induction will have the effect of limited molecular movement, so fiber formation will be slow. This goes hand in hand with the viscosity factor, or solution thickness. Viscosity shows the length of the chain and the number of molecules in the solution. The higher the viscosity value, the more chains form due to solution interactions [38]. This is thought to cause the movement of molecules affected by electrical induction to be slow. This slow molecular movement will make the attractive forces between molecules smaller. If the movement is slow, the solution at the end of the spinneret will clot. This clump prevents the formation of fibers above the collector. Another factor is electric voltage, which is the amount of electrical induction given to the solution to influence the molecular interactions of the solution and the formation of hybrid fibers. Suppose the applied electric voltage is too large. In that case, it can be expected that the chemical bonds between the molecules will be broken too quickly, so the fiber formation process cannot occur continuously. On the contrary, if the applied electrical voltage is too small, the fiber formation process will be slower, and fibers may not even form. Therefore, the electric voltage setting should be adjusted to the characteristics of the solution used [43]. Based on research on gelatin solutions, the electrical voltage should be between 15 and 20 kV. The distance between the spinneret and the collector is 10 cm and 12 cm [44].

This research aims to study the effect of the composition of PVA and oxidized sucrose on the mechanical properties, diameter, and strength of the hybrid fiber produced. The independent variables used in this research include PVA concentration and oxidized sucrose concentration. The dependent variables sought in this research are the diameter of the hybrid fiber, the distribution of compound content in the hybrid fiber, tensile strength, crystallinity, and the thermal properties of the hybrid fiber.

2- Material and Methods

2-1- Material

In this research, materials used include gelatin from beef bones, chitosan from Sigma Aldrich, polyvinyl chloride (PVA) from Sigma-Aldrich P1763-250G, sucrose from Merck, sodium periodate from Merck, ethanol from Sigma Aldrich, aquades. The equipment used includes a set of electrospinning tools, magnetic stirrer, TGA, Universal Testing Machine (UTM) for tensile testing tool model WDW-5 Class 1 serial number 201702016, XRD with the specification from Bruker D8 Advance, viscometer from Brookfield, multimeter from Zoyi ZT219 TRMS, scanning electron microscope (SEM EDX) from JEOL JSM-6360 and Fourier transform infrared spectroscopy (FTIR) from Shimadzu Japan.

2-2- Methods

- *Synthesis of oxidized sucrose (OS);*

  Oxidixed sucrose prepared by weighing 3 g of sucrose which dissolved in 50 ml of distilled water (0.01 mol), then oxidized with 0.02 mol $NaIO_4$ (0.416 g) and left in the dark for 6 hours.

- *Synthesis and Production process for making hybrid fiber using coaxial electrospinning;*

  To Produce hybrid fiber using a set of coaxial electrospinning as shown in Figure 6. The schema for coaxial electrospinning can be seen in Figure 7. The specifications of the electrospinning tool include one syringe with a size of 10 mL and a needle diameter of 0.8 mm. The distance between the noodles and the drum collector is 6 cm, with a flow rate of 1 mL/hour. The diameter of the collector drum is 20 cm. The process is carried out under operating conditions at room ambient temperature, using a fixed electric current of 6 mA for 6 hours.

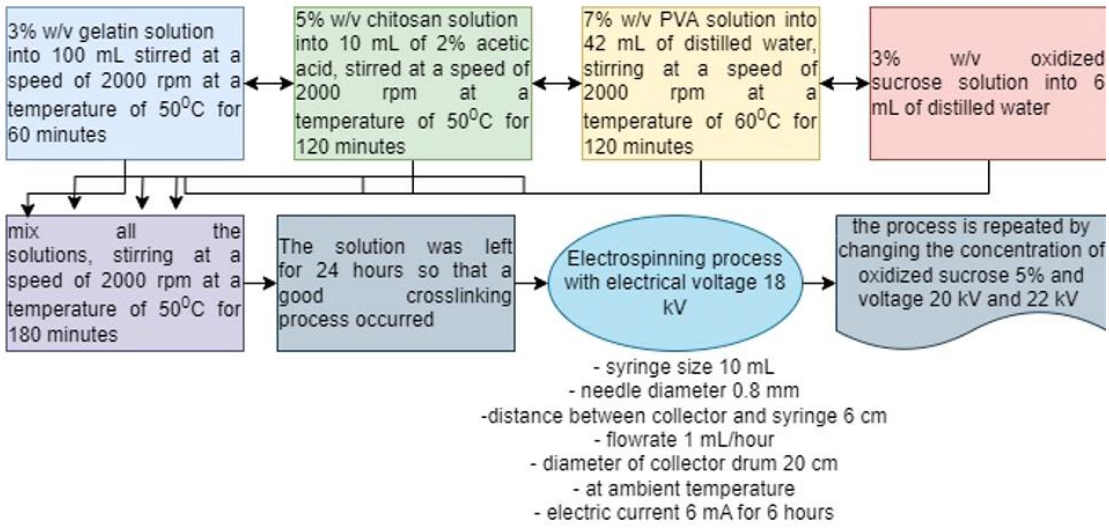


Figure 6. Flowchart of methodology

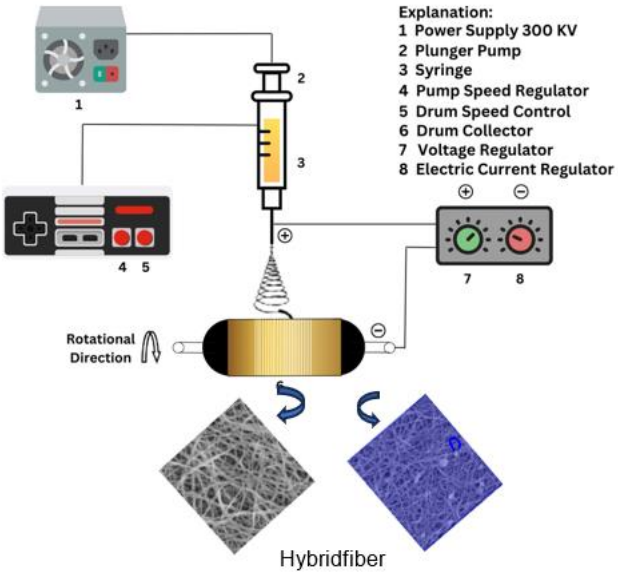


Figure 7. Design of Coaxial Electrospinning

- *Hybridfiber Characterization:*

Surface Morphology and Determining the Diameter of Hybridfiber

To determine the morphology and fiber diameter, a SEM tool from JEOL-JCM 7000 Kyoto, Japan, was used. To measure fiber diameter, use ImageJ software.

Fourier Transform Infrared Spectroscopy (FTIR)

The existence of new functional groups and the changing of chemical structure formed from the reaction of the materials used Fourier transform infrared spectroscopy (FTIR). The resolution of over a range of 4000 cm^{-1}-500 cm^{-1}. The FTIR spectroscopy sample was prepared by cutting the HF sample with a size of 2 × 2 cm, then pelleted with KBr and scanned at 25°C. The variation of main groups of the HF molecule with different solutions was characterized by FTIR spectroscopy Shimadzu, IRSpirit, from Kyoto, Japan. Measurements were performed at room temperature and relative humidity of less than 40%.

Thermal analysis (TGA)

The thermal behaviors of webs are observed by thermogravimetric analysis (TGA) throughout a temperature range between 100^0C-500^0C.

X-Ray Diffraction XRD analysis

XRD analysis was carried out by placed in the test sample holder. The diffractometer voltage used is 40 kV and the current is set at 15 mA. The scanning angle with 2θ is 5° to 50°, and the scanning speed is 1°/min, the scanning frequency is 0.01/1° [40].

Data Processing and Analysis

The data obtained were assessed for tensile strength, Young's Modulus, mass, thickness, sample diameter, elemental composition, presence of functional groups, sample decomposition percentage at various temperatures, and crystallinity properties. Data processing used Design of Experiment and SPSS software.

3- Result and Discussion

- ***Production of PVACOS hybridfiber***

PVACOS hybrid fiber provides good performance results. The results of measuring the diameter distribution of the hybrid fiber are shown in Figure 8. Based on Figure 8, it can be seen that the diameter of the material containing PVACOS is smaller than that without PVACOS. It is close to nano size, so it has the potential to become a nanomaterial. Material containing 5% PVACOS composition has an average hybrid fiber diameter of 0.32 µm, while 3% PVACOS has a hybrid fiber diameter of 0.33 µm. As a comparison, the ge-Ch-PVA composition produces an average diameter of 0.3752 nm, while the ge-ch composition has a diameter of 0.40495 nm. This shows that the PVACOS combination can reduce the size of the material so that it is very effective as a medical thread material. If a medical thread has a small diameter, it will be easier to absorb in the body, thereby helping the cell proliferation process. This phenomenon can also be carried out by nanometer-sized materials [45-48]. Figure 8 shows that the higher the OS concentration, the better the uniformity of the hybrid fiber, and the presence of beads also becomes smaller or disappears. This performance is essential to apply, especially in the medical world.

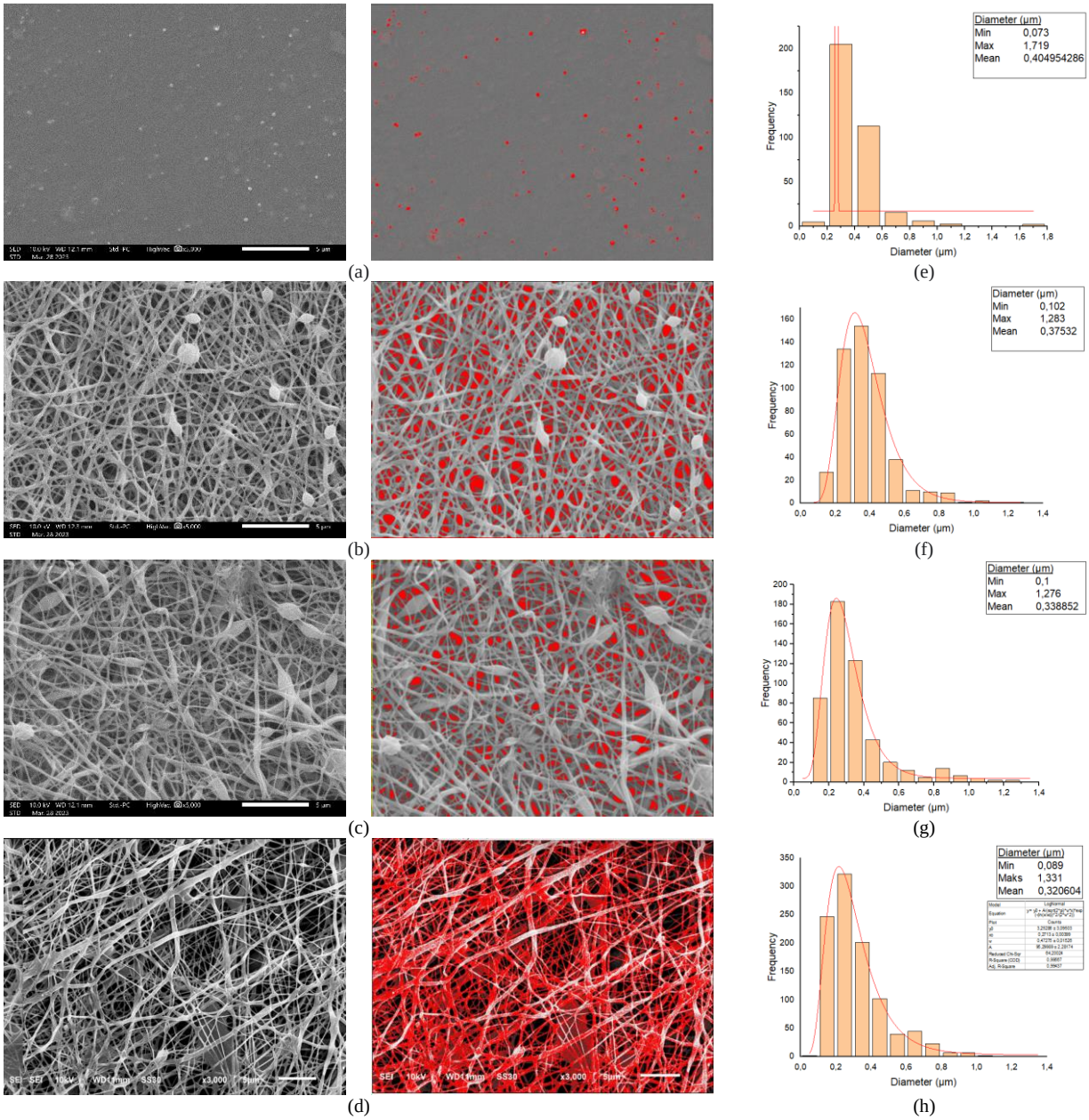


Figure 8. SEM Image of Morphology (a) hybridfiber Ge 3%-Ch 5% (b) hybridfiber Ge 3%-Ch 5%-PVA 7% (c) hybridfiber Ge 3%-Ch 5%-PVA 7%-OS 3%; (d) hybridfiber Ge 3%-Ch 5%-PVA 7%-OS 5%; (e-h) Presented the diameter distribution of hybridfiber corresponding to image (a), (b), (c), and (d) respectively.

The morphological structure for the Ge-PVACOS 3% composition has a discontinuous texture and beads. This is because the solution does not have enough force to evaporate, so it cannot form fibers when it reaches the drum collector. The diameter is around 0.3388 µm or about 338 nm. The average diameter resulting from this synthesis is 338 nm. The distribution of diameter distribution is relatively uneven, still random. The SEM EDX results are also presented in Figure 9. The distribution of each component is shown in Table 2.

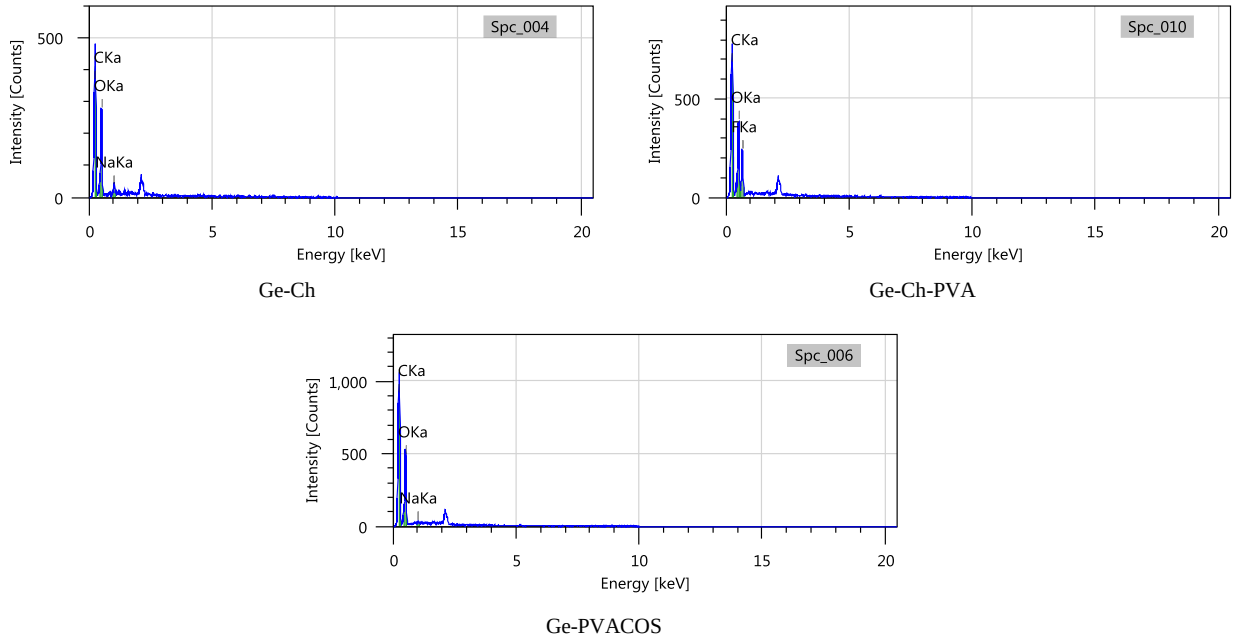


Figure 9. SEM EDX Composition of Hybridfiber Material

Table 2. Distribution of Elements C and O

Material	Element				
	%Mass C	%Mass O	%Mass Na	%Mass F	Total
Ge-Ch	41.92±1.46	55.18±3.47	2.90±0.72	-	100.00
Ge-Ch-PVA	45.31±1.04	54.10±2.46	0.59±0.24	-	100.00
Ge-PVACOS	38.09±1.01	33.76±1.85	-	28.16±2.07	100.00

Table 2 shows that oxygen atoms, namely 55%, dominate the material resulting from Ge-Ch electrospinning. The PVACOS hybridfiber material has a relative composition: C atoms of 38.09 ± 1.01, O atoms of 33.76 ± 1.85, and F atoms of 28.16 ± 2.07. The addition of oxidized sucrose shows a significant effect, including improving mechanical properties without changing the structure of the nanofibers formed, increasing thermal strength, non-toxic properties, and increasing bacterial inhibition. In the coaxial electrospinning process, parameters such as solution composition, solution concentration, flow rate, electric current, voltage, and distance of the spinneret to the collector drum have an essential influence. This will affect the diameter and gaps between the resulting hybrid fibers.

- ***Mechanical Characterization***

The combination of gelatin material with PVACOS provides excellent performance. This increases the tensile strength characteristics of the hybrid fiber. Periodic oxidation sucrose (OS) is a good crosslink agent. The OS agent experienced increased binding intensity with gelati. The NH_2 amine group in gelatin bonds with oxidized sucrose (OS) in the hydroxyl group. Figure 10 shows the crosslinking process of gelatin with oxidized sucrose, while Figure 11 shows the results of the FTIR spectrum of pure sucrose compounds with sucrose that have been oxidized with periodate. The absorption intensity at a wavelength of 1718 cm^{-1} illustrates that there are cytotoxic residual substances. This is produced from the remaining oxidized sucrose that does not successfully crosslink with PVACOS. This phenomenon occurs because the solution medium is still too dilute, so there is still a lot of distilled water solvent, and it cannot crosslink perfectly with oxidized sucrose.

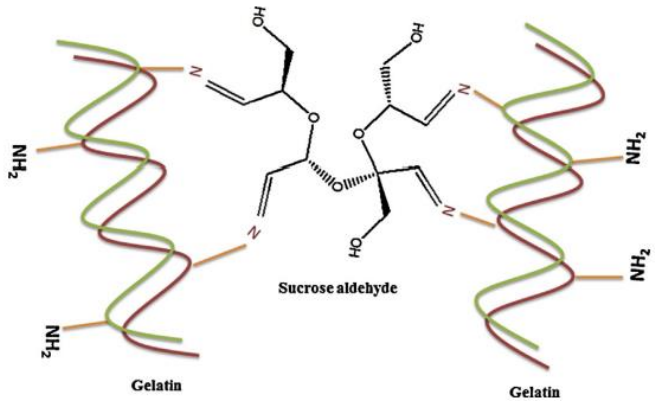


Figure 10. Crosslink Mechanism of Gelatin with OS [38]

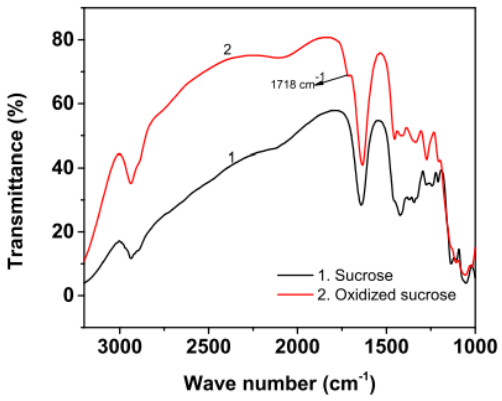


Figure 11. Comparison Of FTIR Spectrum of Sucrose and OS [38]

The tensile strength test will provide limits on the physical characteristics that are allowed when using hybrid fiber. In Indonesia, the permissible tensile strength value for medical textiles is between 19.5 MPa to 87.1 MPa. In this research, one of the objectives of using OS is to increase the tensile strength of hybrid fiber. Based on the study, the tensile strength value was obtained, as shown in Figure 12.

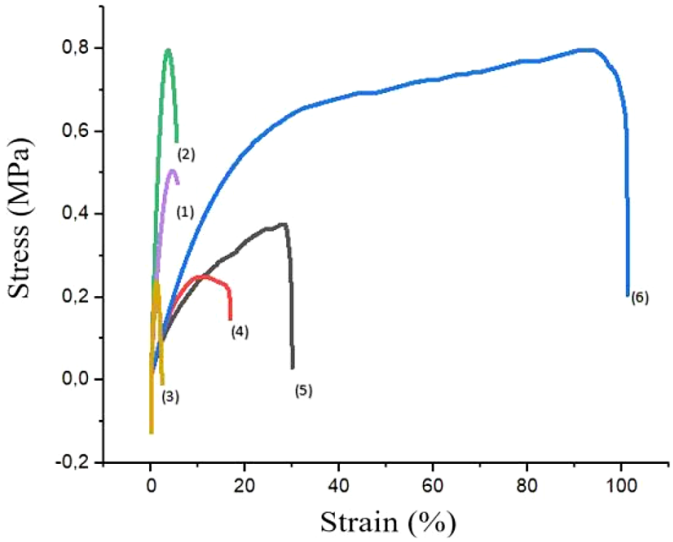


Figure 12. Tensile Test Behaviour of Hybrid fiber

Figure 12 explains the stress-strain strength of hybrid fiber materials with different OS concentrations and voltages. Young's modulus strength is summarized in Table 3. Hybrid fiber materials number 1 to number 3 have relatively weak tensile strength, while numbers 4 to 5 have tensile strength values by permitted medical textile standards. Hybrid fiber material number 6 has a tensile strength value that exceeds medical textile standards. An increase in the voltage used tends to increase the tensile strength. Increasing the OS concentration will increase the crosslink strength of the PVACOS hybrid fiber material, resulting in a higher tensile strength.

Table 3. Tensile Test Result

No.	Type of Sample	Elongation at Break (%)	Ultimate Strength (MPa)	Modulus Young (N/m^2)	Mass of Hybridfiber (mg)	Thickness (µm)
1	Ge-PVACOS 3% 22 kV	4.84	0.502318	9.635331	0.3368	14.2380
2	Ge- PVACOS 3% 20 kV	3.724	0.795025	4.684127	1.1356	55.9047
3	Ge- PVACOS 3% 18 kV	0.916	0.225241	4.066758	0.9392	55.2809
4	Ge- PVACOS 5% 18 kV	9.9	0.248	39.91935	1.0826	45.8285
5	Ge- PVACOS 5% 20 kV	28.516	0.374594	76.12507	0.7986	69.8973
6	Ge- PVACOS 5% 22 kV	95	0.790659	120.153	1.0643	50.8095

Research by Khanlou et al. [48] suggests that increasing the concentration of the polymer solution will provide excellent and smooth hybrid fiber formation performance. This performance will decrease if the flow rate and voltage of the polymer are increased. This will cause many beads to occur, affecting the thickness of the hybrid fiber. Increasing the number of beads has the effect of increasing the thickness of the hybrid fiber. Compared with research conducted by

Ahmadipourroudposht et al. [49], the voltage-produced a hybrid fiber with almost the same thickness, namely 45 kV. Meanwhile, this research displays a lower voltage, namely 22 kV, making it more economical.

- ***FTIR and Thermal Characterization***

Determination of the most dominant structure or functional group in hybrid fiber is determined using FTIR. This coaxial electrospinning process can produce strong fibers depending on the concentration of the solution. The tendency is that the higher the concentration, the stronger the hybrid fiber will be. This is characterized by increased absorption or absorption intensity in FTIR.

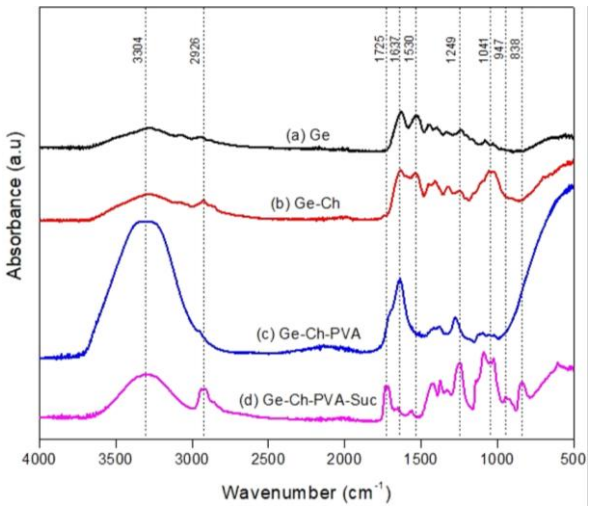


Figure 13. FTIR Absorption of PVACOS Hybridfiber

The crosslinking of gelatin with chitosan or PVA produces different absorption if not crosslinked with PVACOS. The primary amino groups of proteins, namely lysine, and hydroxyproline, will undergo a crosslinking reaction with the aldehyde groups of oxidized sucrose by forming Schiff bases. Oxidized sucrose can provide better performance intensity for hybrid fibers, especially those containing protein. This event is shown in the resulting absorption band in Figure 13. The broad absorption band in the wavelength area of 3500 cm^{-1}-3200 cm^{-1} is the absorption band for the O-H stretching group or hydrophilic/hydroxyl group. This gives the resulting fiber material an excellent opportunity to dissolve in water. At 1720 cm^{-1}-1730 cm^{-1} absorption, there is C=O stretching absorption, which is accompanied by the appearance of peaks at 1637 cm^{-1} and 1530 cm^{-1}, where this is C=O stretching absorption in Amide I and N-H bending together with C-H stretching of Amide II. At an absorption of 838 cm^{-1}, there is a C-O group in the amorphous state. There is a decrease in intensity at 1637 cm^{-1}, possibly breaking the C=C double bond, which is substituted with a C-H bond. This is shown in the absorption band 2900 cm^{-1}-3000 cm^{-1}, which experiences an increase in absorption intensity.

The crystallinity structure of the helical structure of the hybrid fiber was also determined using XRD. This is shown in Figure 14a. The sharp absorption peaks at 2θ=21.2° and 2θ=24.3° indicates high crystallinity. The electrospinning process causes this increase in crystallinity; as the time of the fiber formation process increases, the presence of solvent will decrease, and the thickness of the material will increase so that the level of crystallinity will be higher [46]. Another reason is that the electrical voltage increases when new crystal growth occurs. This triggers the formation of new crystals, characterized by the production of new peaks [47].

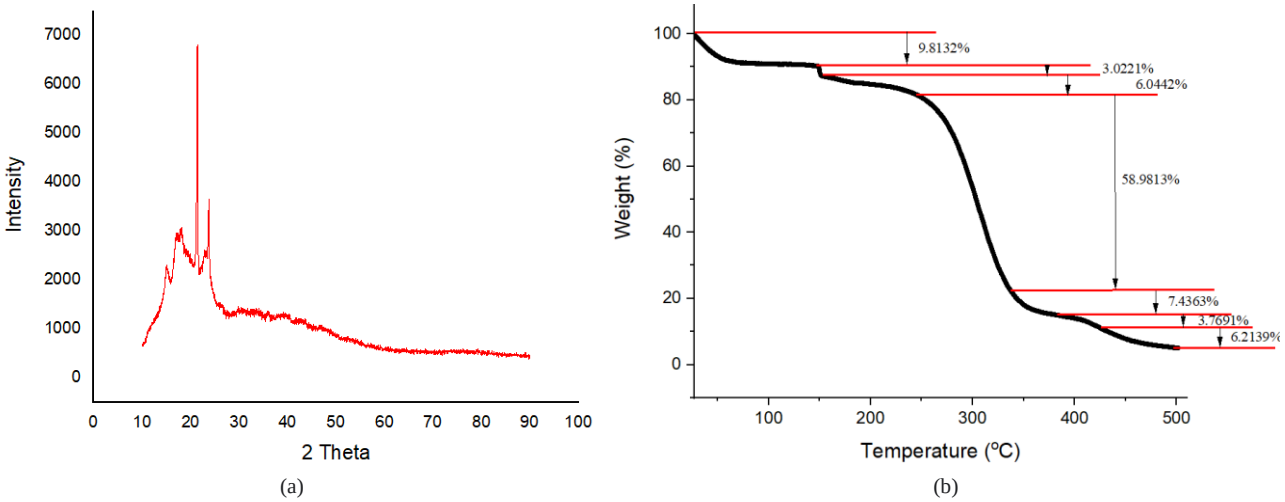


Figure 14. (a) XRD graph of PVACOS 5% 20 kV, (b) TGA graph of PVACOS 5% 20 kV

TGA analysis was carried out to determine the characteristics of PVACOS hybrid fiber regarding temperature. The results are shown in Figure 14b. In the initial material heating stage, there is a mass loss or decomposition of around 9.8132%. This is likely the remaining solvent remaining in the material. At a temperature of 250ºC-320ºC, there was a sharp decrease in material decomposition, namely around 58.981%. This decrease in composition is because, at this temperature, the covalent bonds and hydrogen bonds formed are broken. This split is followed by a loss of mass of the elements contained in the material. Considering that the main composition of this hybrid fiber is dominated by organic molecules, in the temperature range of 200ºC-350ºC, it will experience a melting process. In the temperature range between 400ºC-500ºC, there is a decrease in the percentage of mass decomposition because the percentage of elements has been relatively reduced very much at temperatures below 500ºC.

- ***Statistical Analysis***

ANOVA analysis was carried out to determine the effect of each parameter. The results of the ANOVA analysis were obtained based on statistical analysis, as shown in Table 4. Based on the ANOVA analysis, all the variables used had a significant influence. This is shown from the results of the p-value, namely <0.05.

Table 4. Results of ANOVA analysis

No.	Source	Sum of Squares	Mean Square	F-value	p-value	R^2	
1.	Young's Modulus	1677.13	186.35	4.36	0.0325	0.8487	significant
2.	Mass Hybridfiber	1.16	0.1289	3.83	0.0451	0.8313	significant
3.	Thickness	3711.46	1237.15	3.45	0.0486	0.4431	significant

To determine the influence of each variable on the output, graph plotting was carried out, and a graph was obtained, as shown in Figure 15a. Based on Figure 15a, it can be seen that if the voltage is increased, the tendency for Young's modulus to improve will be higher. The flow rate of the electrospinning treatment will affect the formation of beads. If the flow rate is too large, the solution will form beads more quickly, which will influence the material's thickness so that the material does not form hybrid fibers. A spinning solution concentration that is too high will affect a high viscosity so that the hybrid fiber material has better uniformity, good tensile strength, and high thickness. Increasing the voltage and OS concentration for Figures 15b and 15c will provide a relatively high hybrid fiber thickness. This, of course, depends on the length of the electrospinning process.

Figures 16a to 16c illustrate that the diversity of variables used performs well for the hybrid fiber produced. The normal probability plot and residual plot help explain the validity of the collected data. The residuals fall in a straight line, which indicates that the data are acceptable and also that the data are following a normal distribution.

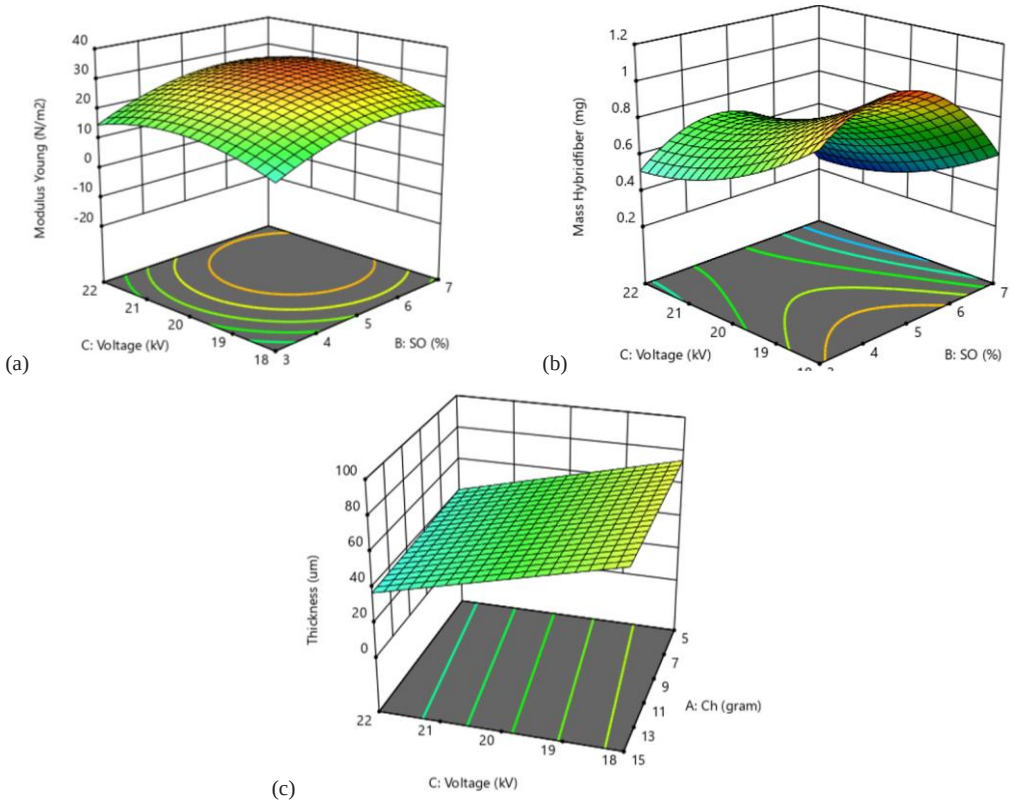


Figure 15. Plotting Graph (a) Young's Modulus (b) Mass Hybridfiber (c) Thickness of hybridfiber

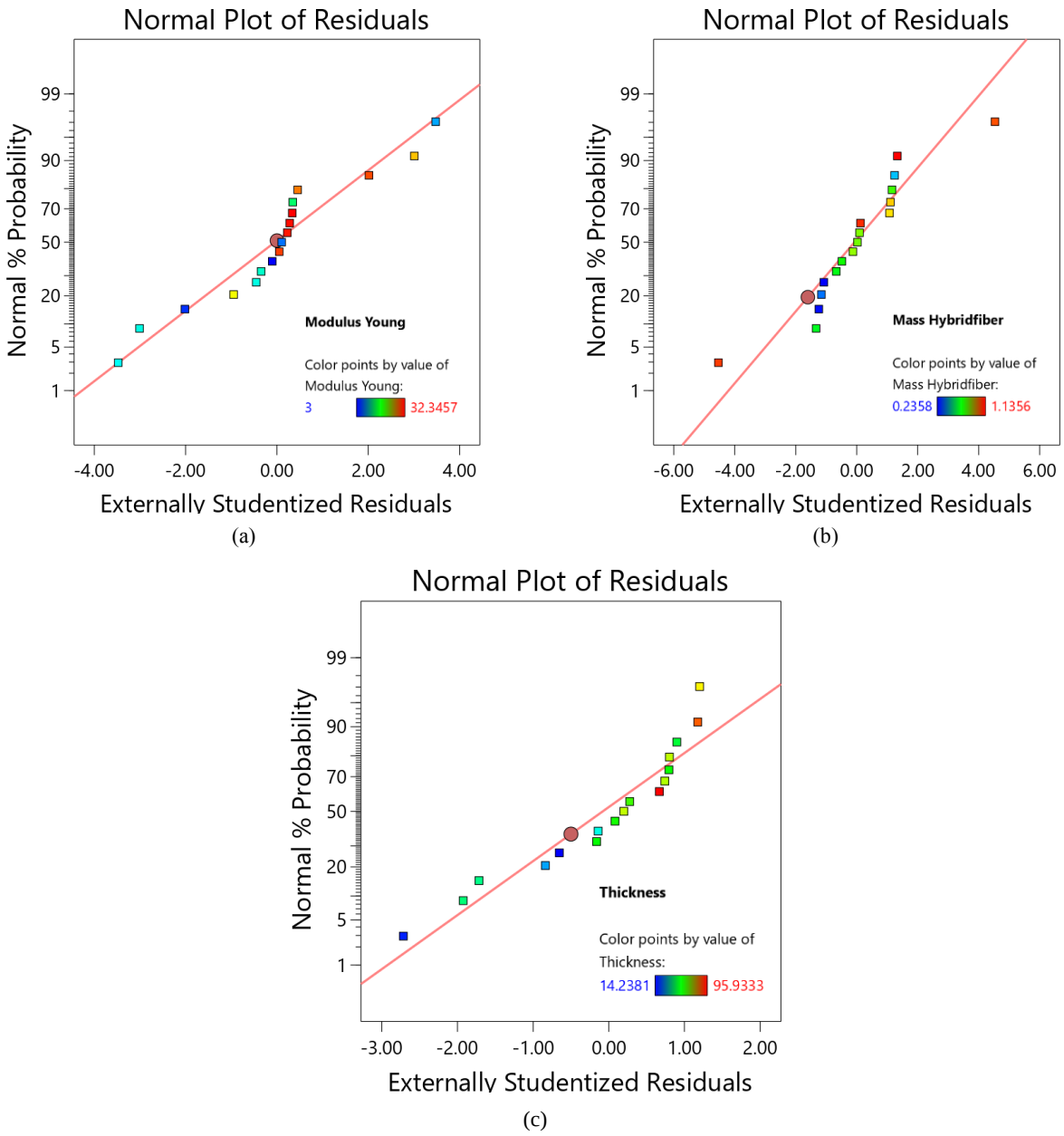


Figure 16. Plotting Graph of Diagnostics Normal Distribution(a) Young's Modulus (b) Mass Hybridfiber (c) Thickness of hybridfiber

4- Conclusion

This research has successfully modified medical textile materials using the coaxial electrospinning method. The coaxial electrospinning process is one of the appropriate methods for building hybrid fiber materials. The operational conditions of this coaxial electrospinning include syringe size 10 mL, needle diameter 0.8 mm, distance between collector and syringe 6 cm, flow rate 1 mL/hour, diameter of collector drum 20 cm, at ambient temperature, electric current 6 mA for 6 hours. In this research, we studied the effect of gelatin composition with PVACOS on the resulting hybrid fiber material. The review was carried out to investigate the performance of diameter, tensile strength (Young's Modulus), thickness, and mass produced.

Based on this research, it was found that to increase the performance of hybrid fiber as a medical textile material, which includes diameter and tensile strength (Young's Modulus), it is necessary to modify gelatin with PVACOS material. In this research, the best hybrid fiber diameter was 320 nm when the gelatin composition with PVACOS was 3%, 7%, 5%, and 5% with the voltage conditions used in electrospinning, namely 18 kV to 20 kV. The same conditions also produce good tensile strength, namely between 39.9 to 76.1 N/m^2. The thickness and mass made under these conditions are 69.89 µm and 0.79 mg, respectively. Physically, the resulting material shows good crystallinity as indicated by XRD performance, which provides absorption at 2θ=21.2° and 2θ=24.3°. The ANOVA test revealed that the hybrid fiber polymer concentration significantly influenced diameter, tensile strength, and thickness. These findings will provide a good contribution as a prototype medical textile material.

4- Declarations

4-1- Author Contributions

Conceptualization, S.F., S.S., M.F., and B.B.; methodology, S.F. and S.S.; software, S.F., S.S., M.F., and B.B.; validation, S.F., S.S., M.F., and B.B.; formal analysis, S.F.; investigation, S.F., S.S., M.F., and B.B.; resources, S.F.; data curation, S.F.; writing—original draft preparation, S.F., S.S., M.F., and B.B.; writing—review and editing, S.F., S.S., M.F., and B.B.; visualization, S.F. S.S., M.F., and B.B.; supervision, S.F. S.S., M.F., and B.B.; project administration, S.F.; funding acquisition, S.F., S.S., M.F., and B.B. All authors have read and agreed to the published version of the manuscript.

4-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

4-3- Funding

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4-5- Institutional Review Board Statement

Not applicable.

4-6- Informed Consent Statement

Not applicable.

4-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

5- References

[1] Meier, P., Zabara, M., Hirsch, C., Gogos, A., Tscherrig, D., Richner, G., Nowack, B., & Wick, P. (2022). Evaluation of fiber and debris release from protective COVID-19 mask textiles and in vitro acute cytotoxicity effects. Environment International, 167, 107364. doi:10.1016/j.envint.2022.107364.

[2] Setiawan, K. (2015). 94 Percent of Surgical Threads in Indonesia are Imported. Tempo Co, Jakarta, Indonesia. Available online: https://gaya.tempo.co/read/702241/94-persen-benang-bedah-di-indonesia-impor (accessed on March 2024).

[3] Parvin, F., Islam, S., Urmy, Z., & Ahmed, S. (2020). A Study on the Textile Materials Applied in Human Medical Treatment. European Journal of Physiotherapy and Rehabilitation Studies, 1, 57. doi:10.5281/ZENODO.3779236.

[4] Durand, D., Faure, M., Lamberton, P., Lemosquet, S., & de Boyer des Roches, A. (2021). A multiparametric approach to assessing residual pain experienced by dairy cows undergoing digestive tract surgery under multimodal analgesia. Animal, 15(9), 100338. doi:10.1016/j.animal.2021.100338.

[5] Baybaş, D., Serdaroğlu, G., & Semerci, B. (2021). The composite microbeads of alginate, carrageenan, gelatin, and poly(lactic-co-glycolic acid): Synthesis, characterization and Density Functional Theory calculations. International Journal of Biological Macromolecules, 181, 322–338. doi:10.1016/j.ijbiomac.2021.03.128.

[6] Sangkert, S., Kamolmatyakul, S., Gelinsky, M., & Meesane, J. (2021). 3D printed scaffolds of alginate/polyvinylalcohol with silk fibroin based on mimicked extracellular matrix for bone tissue engineering in maxillofacial surgery. Materials Today Communications, 26, 102140. doi:10.1016/j.mtcomm.2021.102140.

[7] Jiang, L. B., Ding, S. L., Ding, W., Su, D. H., Zhang, F. X., Zhang, T. W., Yin, X. F., Xiao, L., Li, Y. L., Yuan, F. L., & Dong, J. (2021). Injectable sericin based nanocomposite hydrogel for multi-modal imaging-guided immunomodulatory bone regeneration. Chemical Engineering Journal, 418, 129323. doi:10.1016/j.cej.2021.129323.

[8] Sinsinwar, S., & Vadivel, V. (2021). Development and characterization of catechin-in-cyclodextrin-in-phospholipid liposome to eradicate MRSA-mediated surgical site infection: Investigation of their anti-infective efficacy through in vitro and in vivo studies. International Journal of Pharmaceutics, 609, 121130. doi:10.1016/j.ijpharm.2021.121130.

[9] Ruiz-Tovar, J., Llavero, C., Jimenez-Fuertes, M., Duran, M., Perez-Lopez, M., & Garcia-Marin, A. (2020). Incisional Surgical Site Infection after Abdominal Fascial Closure with Triclosan-Coated Barbed Suture vs Triclosan-Coated Polydioxanone Loop Suture vs Polydioxanone Loop Suture in Emergent Abdominal Surgery: A Randomized Clinical Trial. Journal of the American College of Surgeons, 230(5), 766–774. doi:10.1016/j.jamcollsurg.2020.02.031.

[10] dos Santos, C. H. M., dos Santos Filho, K. G., Cassino, P. C., Chiquetti, C. V., de Mello, A. P., & Dourado, D. M. (2017). Differences between polydioxanone and poliglactin in intestinal anastomoses - A comparative study of intestinal anastomoses. Journal of Coloproctology, 37(4), 263–267. doi:10.1016/j.jcol.2017.05.004.

[11] Mohammadi, H., Alihosseini, F., & Hosseini, S. A. (2020). Improving physical and biological properties of nylon monofilament as suture by Chitosan/Hyaluronic acid. International Journal of Biological Macromolecules, 164, 3394–3402. doi:10.1016/j.ijbiomac.2020.08.081.

[12] Dittmer, S., Paepke, S., Klein, E., Ohlinger, R., & Kiechle, M. (2012). 614 First Experiences with the Implementation of a Two Component Polypropylen-vicryl Mesh (SERAGYN® BR) as Tissue-supporting Extraneous Material in Plastic Reconstructive Surgery. European Journal of Cancer, 48, S224. doi:10.1016/s0959-8049(12)70679-2.

[13] Gressier, P., De Smet, D., Behary, N., Campagne, C., & Vanneste, M. (2019). Antibacterial polyester fabrics via diffusion process using active bio-based agents from essential oils. Industrial Crops and Products, 136, 11–20. doi:10.1016/j.indcrop.2019.04.014.

[14] Lopetuso, L. R., De Salvo, C., Di Martino, L., Rana, N., Goodman, W., Scaldaferri, F., Armuzzi, A., Gasbarrini, A., & Pizarro, T. T. (2018). Oc.02.1 Il-33 Promotes Gut Mucosal Wound Healing By Inducing Mirna-320 To Stimulate Epithelial Restitution and Repair. Digestive and Liver Disease, 50(2), e71. doi:10.1016/s1590-8658(18)30273-1.

[15] Porrelli, D., Berton, F., Camurri Piloni, A., Kobau, I., Stacchi, C., Di Lenarda, R., & Rizzo, R. (2021). Evaluating the stability of extended-pour alginate impression materials by using an optical scanning and digital method. Journal of Prosthetic Dentistry, 125(1), 189.e1-189.e7. doi:10.1016/j.prosdent.2020.06.022.

[16] Zheng, W., Chen, C., Zhang, X., Wen, X., Xiao, Y., Li, L., Xu, Q., Fu, F., Diao, H., & Liu, X. (2021). Layer-by-layer coating of carboxymethyl chitosan-gelatin-alginate on cotton gauze for hemostasis and wound healing. Surface and Coatings Technology, 406, 126644. doi:10.1016/j.surfcoat.2020.126644.

[17] Fatimah, S., Sarto, S., Fahrurrozi, M., & Budhijanto, B. (2023). Characterization and Development of Gelatin from Cow Bones: Investigation of the Effect of Solvents Used for Soaking Beef Bones. Applied Sciences (Switzerland), 13(3), 1550. doi:10.3390/app13031550.

[18] Aksun Tümerkan, E. T., Cansu, Ü., Boran, G., Regenstein, J. Mac, & Özoğul, F. (2019). Physiochemical and functional properties of gelatin obtained from tuna, frog and chicken skins. Food Chemistry, 287, 273–279. doi:10.1016/j.foodchem.2019.02.088.

[19] Hamzah, N., Fadhlurrahman, M., Ningsi, S., & Haeria, H. (2019). Profil Indeks Pengembangan Ikatan-Silang Gelatin-Kitosan. Ad-Dawaa' Journal of Pharmaceutical Sciences, 2(2). doi:10.24252/djps.v2i2.12147.

[20] Bichukale, A. D., Koli, J. M., Sonavane, A. E., Vishwasrao, V. V., Pujari, K. H., & Shingare, P. E. (2018). Functional properties of gelatin extracted from poultry skin and bone waste. International Journal of Pure & Applied Bioscience, 6(4), 87-101. doi:10.18782/2320-7051.6768.

[21] Ahmed, M. A., Al-Kahtani, H. A., Jaswir, I., AbuTarboush, H., & Ismail, E. A. (2020). Extraction and characterization of gelatin from camel skin (potential halal gelatin) and production of gelatin nanoparticles. Saudi Journal of Biological Sciences, 27(6), 1596–1601. doi:10.1016/j.sjbs.2020.03.022.

[22] Mulyani, S., Aristia, K. S., Sabrina, A. P., Arfiah, A., & Niam, B. (2020). Potential of Water Extract of The White Frangipani (Plumeria acuminate) and Hibiscus (Hibiscus tiliaceus) Leaves Powder as Textile Natural Dyes. JKPK (Jurnal Kimia dan Pendidikan Kimia), 5(1), 100-109.

[23] Hatamvand, M., Kamrani, E., Lira-Cantú, M., Madsen, M., Patil, B. R., Vivo, P., Mehmood, M. S., Numan, A., Ahmed, I., & Zhan, Y. (2020). Recent advances in fiber-shaped and planar-shaped textile solar cells. Nano Energy, 71, 104609. doi:10.1016/j.nanoen.2020.104609.

[24] Wang, X., Hou, M., Liu, X., Yue, O., & Zheng, M. (2021). Feasibility Study of Gelatin Preparation from the Bioinspired Collagen Aggregates by a "two-step" Facile Degradation Method. ACS Applied Bio Materials, 4(3), 2363–2372. doi:10.1021/acsabm.0c01215.

[25] Cao, C., Wang, F., & Lu, M. (2020). Preparation of superhydrophobic CuS cotton fabric with photocatalytic and antibacterial activity for oil/water separation. Materials Letters, 260, 126956. doi:10.1016/j.matlet.2019.126956.

[26] Li, P., Wang, B., Liu, Y. Y., Xu, Y. J., Jiang, Z. M., Dong, C. H., Zhang, L., Liu, Y., & Zhu, P. (2020). Fully bio-based coating from chitosan and phytate for fire-safety and antibacterial cotton fabrics. Carbohydrate Polymers, 237, 116173. doi:10.1016/j.carbpol.2020.116173.

[27] Dinh, N. H., Tran, H. Van, & Choi, K. K. (2020). Direct shear behavior of cementitious mortar reinforced by carbon fiber textile. Construction and Building Materials, 249, 118760. doi:10.1016/j.conbuildmat.2020.118760.

[28] Drago, E., Campardelli, R., Barbucci, A., & Perego, P. (2023). Polycaprolactone sub-micrometric fibers optimization for primary packaging loaded with fatty acids as natural phase change materials. Journal of Food Engineering, 358, 111680. doi:10.1016/j.jfoodeng.2023.111680.

[29] Obisesan, O. S., Ajiboye, T. O., Mhlanga, S. D., & Mufhandu, H. T. (2023). Biomedical applications of biodegradable polycaprolactone-functionalized magnetic iron oxides nanoparticles and their polymer nanocomposites. Colloids and Surfaces B: Biointerfaces, 227, 113342. doi:10.1016/j.colsurfb.2023.113342.

[30] Akshay Kumar, K. P., Zare, E. N., Torres-Mendieta, R., Wacławek, S., Makvandi, P., Černík, M., Padil, V. V. T., & Varma, R. S. (2021). Electrospun fibers based on botanical, seaweed, microbial, and animal sourced biomacromolecules and their multidimensional applications. International Journal of Biological Macromolecules, 171, 130–149. doi:10.1016/j.ijbiomac.2020.12.205.

[31] Taheri, P., & Khajeh-Amiri, A. (2020). Antibacterial cotton fabrics via immobilizing silver phosphate nanoparticles onto the chitosan nanofiber coating. International Journal of Biological Macromolecules, 158, 282–289. doi:10.1016/j.ijbiomac.2020.04.258.

[32] Yan, J., He, S., Chen, L., Chen, H., & Wang, W. (2023). Characterization, antioxidant and antibacterial activities of gelatin-chitosan edible coated films added with Cyclocarya paliurus flavonoids. International Journal of Biological Macromolecules, 253, 127664. doi:10.1016/j.ijbiomac.2023.127664.

[33] Yang, H., Tan, X., Du, G., Ni, K., Wu, Y., Li, Z., Ran, X., Gao, W., Li, J., & Yang, L. (2023). Development of biomass adhesives based on aminated cellulose and oxidized sucrose reinforced with epoxy functionalized wood interface. Composites Part B: Engineering, 263, 110872. doi:10.1016/j.compositesb.2023.110872.

[34] Kovačičin, J., Hauzerová, S., Běhálek, L., Lukáš, D., & Kuželová Košťáková, E. (2024). Sponge-like wet electrospun polycaprolactone fibres. Materials Letters, 355, 135460. doi:10.1016/j.matlet.2023.135460.

[35] Tyuftin, A. A., & Kerry, J. P. (2021). Gelatin films: Study review of barrier properties and implications for future studies employing biopolymer films. Food Packaging and Shelf Life, 29, 100688. doi:10.1016/j.fpsl.2021.100688.

[36] Sathisaran, I., & Balasubramanian, M. (2020). Physical characterization of chitosan/gelatin-alginate composite beads for controlled release of urea. Heliyon, 6(11), 5495. doi:10.1016/j.heliyon.2020.e05495.

[37] Nasseri, F., Rokhsat, E., & Dorranian, D. (2016). Low power continues wave nonlinear optics in red BS dye doped PVA thin film. Optik, 127(17), 6813–6820. doi:10.1016/j.ijleo.2016.05.026.

[38] Jalaja, K., & James, N. R. (2015). Electrospun gelatin nanofibers: A facile cross-linking approach using oxidized sucrose. International Journal of Biological Macromolecules, 73(1), 270–278. doi:10.1016/j.ijbiomac.2014.11.018.

[39] Subbiah, T., Bhat, G. S., Tock, R. W., Parameswaran, S., & Ramkumar, S. S. (2005). Electrospinning of nanofibers. Journal of Applied Polymer Science, 96(2), 557–569. doi:10.1002/app.21481.

[40] Xing, J., Zhang, M., Liu, X., Wang, C., Xu, N., & Xing, D. (2023). Multi-material electrospinning: from methods to biomedical applications. Materials Today Bio, 21, 100710. doi:10.1016/j.mtbio.2023.100710.

[41] Ding, B., Yu, J., & Wang, X. (2018). Electrospinning: Nanofabrication and applications. In Electrospinning: Nanofabrication and Applications. Elsevier. doi:10.1016/C2016-0-01374-8.

[42] Gani, B. A., Asmah, N., Soraya, C., Syafriza, D., Rezeki, S., Nazar, M., ... & Soedarsono, N. (2023). Characteristics and antibacterial properties of film membrane of chitosan-resveratrol for wound dressing. Emerging Science Journal, 7(3), 821-842. doi:10.28991/ESJ-2023-07-03-012.

[43] Vaseashta, A., & Bölgen, N. (2022). Electrospun Nanofibers: Principles, Technology and Novel Applications. Electrospun Nanofibers: Principles, Technology and Novel Applications, 1–766. doi:10.1007/978-3-030-99958-2.

[44] Ali, I. H., Elkashlan, A. M., Hammad, M. A., & Hamdi, M. (2023). Antimicrobial and anti-SARS-CoV-2 activities of smart daclatasvir-chitosan/gelatin nanoparticles-in-PLLA nanofibrous medical textiles; in vitro, and in vivo study. International Journal of Biological Macromolecules, 253, 127350. doi:10.1016/j.ijbiomac.2023.127350.

[45] Khadayeir, A. A., Wannas, A. H., & Yousif, F. H. (2022). Effect of Applying Cold Plasma on Structural, Antibacterial and Self Cleaning Properties of α-Fe2O3 (HEMATITE) Thin Film. Emerging Science Journal, 6(1), 75–85. doi:10.28991/ESJ-2022-06-01-06.

[46] Sinha, M. K., Das, B. R., Bharathi, D., Prasad, N. E., Kishore, B., Raj, P., & Kumar, K. (2020). Electrospun nanofibrous materials for biomedical textiles. Materials Today: Proceedings, 21, 1818–1826. doi:10.1016/j.matpr.2020.01.236.

[47] Pato, U., Ayu, D. F., Riftyan, E., Restuhadi, F., Pawenang, W. T., Firdaus, R., Rahma, A., & Jaswir, I. (2022). Cellulose Microfiber Encapsulated Probiotic: Viability, Acid and Bile Tolerance during Storage at Different Temperature. Emerging Science Journal, 6(1), 106–117. doi:10.28991/ESJ-2022-06-01-08.

[48] Khanlou, H. M., Ang, B. C., Talebian, S., Barzani, M. M., Silakhori, M., & Fauzi, H. (2015). Multi-response analysis in the processing of poly (methyl methacrylate) nano-fibres membrane by electrospinning based on response surface methodology: Fibre diameter and bead formation. Measurement: Journal of the International Measurement Confederation 65, 193–206. doi:10.1016/j.measurement.2015.01.014.

[49] Ahmadipourroudposht, M., Fallahiarezoudar, E., Yusof, N. M., & Idris, A. (2015). Application of response surface methodology in optimization of electrospinning process to fabricate (ferrofluid/polyvinyl alcohol) magnetic nanofibers. Materials Science and Engineering C, 50, 234–241. doi:10.1016/j.msec.2015.02.008.