



**SYNTHESIS AND CHARACTERIZATION OF SOY PROTEIN CONCENTRATE  
RESINMODIFIED WITH C 30B REINFORCED GELLAN**

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**ABSTRACT**

Soy protein concentrate (SPC) resin was modified successfully by phytigel and nano-clay particles to improve the mechanical and thermal properties and moisture resistance. SPC and Phytigel were mixed together to form a cross linked structure. The Gellan (Commercial name Phytigel)-modified SPC resin (PHY-SPC) showed improved tensile strength, modulus and moisture resistance, as compared to the unmodified SPC resin. The incorporation of 50% Phytigel and 20% glycerol led to an overall 350% increase in both the tensile strength (over 45MPa) and Young's modulus (over 870MPa) of the SPC resin. Nano-clay was uniformly dispersed into PHY-SPC resin to further improve the properties. The PHY-SPC (50% Phytigel) resin modified with 5% clay nanoparticles (CPHY-SPC) had a modulus of 2.2 GPa and a strength of 74.0MPa. The moisture resistance of the CPHY-SPC resin was higher as compared to both SPC and PHY-SPC resins. The thermal stability of the CPHY-SPC resin was seen to be higher as compared to the unmodified SPC.

**Keywords: Soy Protein Concentrate (SPC) Resin, Gellan, Claynanoparticles**

**INTRODUCTION**

Every year, large amounts of non-biodegradable plastic wastes are discarded, which have led to environmental problems. Their incineration generates toxic air pollution, whereas satisfactory landfill is limited. The use of biodegradable materials can help to solve these problems, because

they can be degraded in the environment by humidity and the action of microorganisms. Recently, the research and development of biodegradable materials from renewable resources, including cellulose [1], starch [2], and protein [3, 4] have attracted more and more attention. Under this background,

because of abundance, low cost, and good biodegradability, soy products such as soy oil, soy protein isolate (SPI), soy whole flour (SWF), soy dreg (SD) and soy protein concentrated (SPC) have been considered as alternatives to petroleum polymers [5, 6]. Use of soy protein as plastics can be traced back to the 1930s [7, 8], and the usual ways to process soy protein plastics are compression-molding and screw-extrusion [9, 10]. Soy protein plastics exhibit good biodegradable performance, but are brittle and water sensitive which make it very difficult to prepare soy protein plastics with good mechanical properties and water resistance [11].

Two major drawbacks of soy protein, which have severely limited its commercial applications, are its high brittleness and moisture sensitivity [12-14]. Soy protein contains several amino acids containing hydrophilic groups, which make soy protein products very moisture sensitive. Without plasticizer, the brittleness of soy protein products makes it very difficult to process. Because of its brittleness, both fracture strain and strength of soy protein are low. Extensive research has been conducted to modify commercially available soy protein products, such as soy protein concentrate (SPC) and soy protein isolate (SPI) [13-16]. SPC contains 68-72% proteins, 19-21% carbohydrates, 4-6% moisture, 0.5-1.0% crude free lipids, 3.4-4.8% crude

fibers, and 3.8-6.2% ashes.15 Glutaraldehyde has been used to cross-link soy protein molecules to increase mechanical properties and lower moisture resistance [17]. Polyphosphate has also been used to improve the stiffness and moisture resistance of soy protein [18]. Incorporating stearic acid into soy protein has also been shown to reduce the moisture sensitivity of SPI due to the inherent hydrophobic nature of the stearic acid [18]. Gellan is an exocellular heteropolysaccharide produced by fermentation [19]. The native gellan is produced by the bacterium species known as *Pseudomonas* [20]. The native gellan produced from *Sphingomonas paucimobilis* composed of a linear repeating tetrasaccharide sequence of D-glucose, D-glucuronic acid, and L-rhamnose in the ratio of 2:1:1 [20]. Gellan forms weak gels in water in the absence of salts. However, in the presence of monovalent or divalent ions, a strong gel is formed through ionic and hydrogen bonds. Appropriate cations screen the electrostatic repulsion between the ionized carboxylate groups and serve as cross-linking points to cross-link the polysaccharide helix structure [21, 22]. Gellan is commercially sold by Sigma under the brand name of Phytigel, which is commonly used as a gelling agent substitute for agar [19, 20]. It can form a colorless high-strength gel in water in the presence of cationic ions. In the presence of salts,

carboxylate groups interact with the ions and act as crosslinking points. Intra- and intermolecular hydrogen bonding can also be formed through the hydroxyl and carboxyl groups. The carboxyl groups on glucuronic acid can also react with the amine, hydroxyl, and carboxyl groups present in soy protein under specific pH conditions [23]. The hydroxyl and carboxyl groups in Phytigel can also form hydrogen bonding with some hydrophilic groups on SPC [23]. Nanocomposites, with nanoparticles dispersed, have been studied extensively due to their capability to improve mechanical, physical, thermal, and barrier properties with very low nanoparticle loading of 1-5 wt % [24-28]. For such composites, montmorillonite (MMT) and other clay nanoparticles have been used by many researchers [29]. With a structure of stacked platelets and one dimension of the platelet in the nanometer scale, MMT has a high aspect ratio when exfoliated. If the platelets are dispersed properly, its nano size can provide a significant amount of interface between the clay and the matrix resin with only a small weight percentage of MMT. This contributes to the excellent mechanical and physical properties of the nanocomposites [29-30].

In the present research, SPC-based resin was modified in two steps. In the first step, Phytigel was used to form a cross-linked structure with SPC. The effect of Phytigel

on the mechanical and thermal properties of the SPC resin was studied. In the second step, the Phytigel modified SPC was further modified using nano-clay to form nanocomposite and thus improve its properties. Here we used Cloisite 30B (C 30B) which is organically modified sodium in MMT with quaternary ammonium salt (the organic modifier in Cloisite 30B is methyl, tallow, bis-2 hydroxyethyl, quaternary ammonium, where tallow is 65% C18, 30% C16, and 5% C14) [4] to enhance the compatibility of the nano clay with the polymer matrices. The nanocomposite material was characterized for its mechanical and thermal properties, and moisture resistance.

#### MATERIAL AND METHODS

SPC powder was provided by Archer Daniels Midland Co., Decatur, IL, as a gift sample and was used for the reaction. Analytical grade of Gellan (Commercial name "Phytigel") was acquired from Sigma-Aldrich Co., St. Louis, MO. Analytical grade glycerol was obtained from Fisher Scientific, Pittsburgh, PA. Both chemicals were used as received. The clay used in this study was organically modified montmorillonite clay (Cloisite 30B, Southern Clay Products). This material was prepared by the supplier through ion-exchanging  $\text{Na}^+$  montmorillonite (with a reported cation exchange capacity of 0.95 mequiv/g) with methyl tallow bis-2-

hydroxyethyl ammonium. The tallow used was composed of ca. 65% C18, 30% C16, and 5% C14 units.

### **Preparation of Nano-Clay and Phytigel-Modified SPC Resin**

Pure SPC resin was prepared by mixing SPC powder with distilled and deionized water in a ratio of 1:15 by weight. To make SPC processable and reduce its brittleness, a specified amount of glycerol was added as a plasticizer. SPC suspension was homogenized via a magnetic stirrer for 30 min. The suspension was then kept in a water bath at 75 °C for 30 min. This process is called the “procuring” of SPC resin. The “procured” SPC suspension (or slurry) was cast onto Teflon-coated glass plates and dried in an air-circulating oven at 35°C for 16 h. The thickness of the sample sheets was controlled by spreading the SPC sample suspension with 7 g solid content onto the 18 cm x 18 cm bowl-like Teflon-coated glass plate mold. Because of the low viscosity of the SPC suspension, it can spread in the mold uniformly and the dried SPC sheets have very even thickness. The dried SPC sheets were finally hot pressed (cured) on a Carver hydraulic hot press for 25 min at 120°C under a pressure of 7 MPa. Thicknesses of the cured SPC sheets varied between 0.12 and 0.13 mm. The Phytigel-modified SPC resin (PH-SPC) was prepared in a similar way. Varying amounts of Phytigel (5%, 10%, 20%, 30%, 40%, and

50%, all of the percentages in this research refer to the weight percentage based on SPC) were dissolved in distilled water to form a solution or weak gel, which was then added to the initial SPC suspension (with glycerol) prepared by the steps described above. The precuring was achieved by reacting the mixture at 75°C for 30 min. The precured PH-SPC sheets were dried and cured using the same procedures described as above for SPC. To study the plasticization effect and find out the optimum working percentage, glycerol was added in various proportions (5%, 10%, 15%, and 20%). Before preparing the clay-modified PH-SPC nanocomposites (CPHSPC), Cloisite30B particles were purified. The particles were first dispersed into distilled and deionized water using a magnetic stirrer and ultra sonication. One gram of clay was dispersed into 200 mL of water by magnetic stirring for 10 h. The clay slurry was then further ultrasonicated for 30 min to improve dispersion and further exfoliation.

The resulted clay suspension (slurry) was stabilized for 1 week before removing the non exfoliated, larger aggregates that settled down. A freeze-drier was used to get the purified nano-clay powder from the stabilized slurry. The purified clay powder was re-dispersed into the distilled water in a weight ratio of 1:100 to form a yellowish clay slurry, which was stable due to the

Brownian motion of the fully exfoliated dispersed nanosized particles and ready for dispersion in SPC resin. The SPC powder and Phytigel were first dispersed into distilled water separately and then mixed together using a magnetic stirrer. The uniform mixture was precured at 75°C for 25 min. Various amounts of dispersed clay slurry were directly introduced into the precuring mixture. Another 5 min was needed to complete the precuring step and to obtain good nano-clay particle dispersion. The final solution with different clay loadings was dried into sheets and cured using the same procedure as described above for SPC sheets. All cured SPC and modified SPC resin sheets were conditioned at 21°C and 65% relative humidity (R.H.) for 72 h prior to characterizing their tensile properties and moisture content. All other characterization methods such as thermal properties and dynamic mechanical properties were conducted without conditioning the specimens.

### Characterization

An Instron tensile tester was used to characterize the tensile properties of SPC and modified SPC resins. The effect of Phytigel content, nanoparticle loading, and glycerol content on tensile properties was studied. Fracture stress, fracture strain, and Young's modulus of the modified SPC resins were measured according to ASTM D 882-97. The test specimens (strips) were cut

to dimensions of 10 mm x 80 mm. The thickness of the specimens varied between 0.12 and 0.13 mm. The gauge length for tensile tests was set at 50 mm, and the strain rate was 0.5/min. All specimens were conditioned according to ASTM 1776 at 21°C and 65% R.H. for 3 days before testing. Moisture content was recorded to understand the moisture sensitivity of the modified SPC resins. A Brabender moisture/volatiles tester (model 1153) was used according to ASTM D 2654-89a to obtain moisture content. A 10-g specimen was used for this test. After being dried in the oven chamber for 24 h at 105°C, the specimen moisture content was read directly from the scale. Thermal stability of the modified SPC resins was characterized using a thermo gravimetric analyzer (TGA), TA Instruments (model 2050, New Castle, DE). A nitrogen environment was maintained during the TGA study. The scanning temperature range was set to be 25-450°C, and the specimens were scanned at a ramp rate of 10°C/min.

Wide-angle X-ray diffraction (WAXRD) was used to evaluate the nanoparticle dispersion. The general area detection diffraction system (GADDS, Bruker-AXS, Inc., Madison, WI) was used at 45 kV and 40 mA. The X-ray diffraction patterns of the resin specimens were obtained using a Scintag  $\theta$ - $\theta$  powder diffractometer (PAD X, Scintag, Inc., Cupertino, CA) with a solid-state

intrinsic germanium detector. The specimen films were scanned from 1° to 40° at 2°/min employing the Cu K $\alpha$  X-ray radiation with a wavelength of 1.5405 Å. The *d* spacing information was recorded. Nano-clay dispersion within the resin was also confirmed via a LEO 922 energy filtered transmission electron microscope (EFTEM). The CPHY-SPC films were embedded in a potting epoxy resin and cut into thin specimens by using a microtome. A 300 mesh copper grid was used to hold the SPC specimens for TEM.

## RESULTS AND DISCUSSION

### Effect of Phytigel on the Mechanical Properties and Moisture Absorption of PHY-SPC Resin

PHY-SPC resin was prepared with 20% glycerol (as a plasticizer) at a neutral pH. The tensile properties and moisture content of the resin are listed in **Table 1**. It can be seen from the data presented in **Table 1** that, as the amount of Phytigel increased from 0% to 50%, Young's modulus and fracture stress increased from 192 to 742 MPa and 13.2 to 48.1 MPa, respectively. At the same time, the fracture strain decreased from 22.4% to 13.7%. It was realized that further increase in Phytigel content did not lead to significant increases in the Young's modulus or the fracture stress.

The gellan-agarose system has been found to form a molecularly interpenetrating

network (IPN)-like structure [31-34]. In an IPN structure, polymer networks partially or completely interpenetrate each other on a molecular scale. Although there is no covalent bonding between different networks, it requires the breaking of polymer bonds to separate the cross-linked polymers. Both SPC (or SPI) and Phytigel, separately, form cross-linked systems [19, 23]. When mixed together, an interpenetrating network-like (IPN-like) structure can be formed [23]. The blend was uniform, and there was no evidence of any kind of physical phase separation based on the visual observation or the stress-strain (tensile) curves. At high temperature, Phytigel in solution, is in the coil form [35]. However, because of the polar amino acids in soy protein, Phytigel can also form strong interactions with SPC chains by hydrogen bonding and possibly through covalent bonding [23]. The hydroxyl groups on rhamnose and glucose provide the active sites for hydrogen bonding. The carboxyl groups present in the glucuronic acid unit are capable of reacting with hydroxyl and carboxyl groups in other Phytigel molecules as well as hydroxyl, carboxyl, and amine groups in SPC molecules to form covalent or hydrogen bonds during the curing process. In addition, the carboxylates in Phytigel molecules provide active sites for ionic linkages. As noted earlier, cationic ions are needed to form a gel structure for

Phytigel [19, 20]. The ashes and other impurities present in the SPC seem to be sufficient to provide cationic ions to promote crosslinking so as to allow the formation of a gel. No additional inorganic ions were employed in this research because a highly cross-linked structure would increase the brittleness of the modified SPC, resulting in lower stress. SPC molecules can penetrate into the gelled Phytigel structure and vice versa to form the IPN-like structure. Different SPC molecules are also capable of cross-linking with each other through hydrogen bonding, disulfide linkage, and other covalent bonding (e.g., ester) formed during the hot process. The stability of IPN structures depends on the relative cohesive energy densities of the two materials [36]. The formation of strong hydrogen bonding between two materials stabilizes the entanglements. In addition, the toughness of the SPC increased with the addition of Phytigel as well. The toughness of a polymer was determined by the area under the stress-strain curve. This area measures the energy required to fracture the material in tensile mode. PHY-SPC with 50% Phytigel showed a toughness of 5.4MPa, which was about 68% higher than the SPC resin without Phytigel. The moisture content of the modified SPC resin decreased from 14.2% to 13.6%. The moisture content of pure Phytigel resin was measured to be 10.5%. The interaction and

cross-linking of polar groups, such as hydroxyl and carboxyl groups, on Phytigel with SPC is believed to have decreased the overall polarity and moisture sensitivity of the modified SPC resin. Water has been shown to be a good plasticizer for soy protein polymers [37]. As a result, the reduction in moisture content with the addition of Phytigel could be another factor to help increase the stiffness of the PHY-SPC. Because further increasing Phytigel content reduced specimen processibility, due to high viscosity, but did not increase the tensile properties of PHY-SPC resin significantly, 50% Phytigel content was selected for further modification of PHY-SPC with nano-clay.

#### **Study of the Effect of Glycerol on the Mechanical Properties and Moisture Resistance of PHY-SPC Resin**

Glycerol has been shown to be effective in plasticizing soy protein resins [38, 39]. Its high polarity due to the hydroxyl groups also increases the moisture absorption by the resin. Soy protein has both polar and nonpolar side chains. Polar groups are responsible for the moisture sensitivity of soy protein products. The polar attractions also increase the stiffness and brittleness of soy protein when no plasticizers are present. Glycerol penetrates into the polymer structure and improves the mobility of soy protein polypeptide chains, resulting in the plasticization effect [38].

As mentioned earlier, for this study, Phytigel content was maintained at 50%. The effect of glycerol on the mechanical properties and moisture absorption by PHY-SPC resins is presented in **Table 2**. As the amount of glycerol in the resin was increased from 5% to 20%, the Young's modulus and fracture stress of the PHY-SPC resin decreased from 2122 to 878MPa and from 57.7 to 53.2 MPa, respectively, the fracture strain also increased from 5.5 to 14.4. The highest fracture stress was observed for the specimen containing 15% glycerol. Although further decreasing glycerol content from 15% to 5% increased the modulus, the fracture stress decreased due to the reduced fracture strain of the specimens. As mentioned earlier, glycerol is very moisture sensitive. It is clear from **Table 2** that the reduction of glycerol content lowered the moisture content of the PHY-SPC. Once glycerol was reduced from 20% to 5%, the moisture content of the specimen was reduced to 14.9% from about 13.7%. Lower moisture content is another factor for the higher strength and modulus of PHY-SPC resin. Our preliminary study with other polysaccharides, for example, chitosan, showed some improvements. Chitosan can form hydrogen bonds, but it is not capable of forming IPN-like structure with SPC. Also, it cannot form ionic bonds.

#### **Effect of Nano-Clay Loading on the Mechanical Properties and Moisture**

#### **Resistance of CPH-SPC Nanocomposite Resin**

The effect of nano-clay on the mechanical properties of the resin is primarily determined by its degree of dispersion in the matrix [40, 42]. Exfoliated nano-clay platelets (particles) have a thickness of approximately 1 nm with the other two dimensions in the range of several hundred nanometers. This results in a large aspect ratio and high interfacial interaction between the polar polymeric matrix and polar clay particles. The dispersion of nano-clay in polymeric matrix also results in the high tortuosity for the polymeric molecules. These two factors contribute to the increased mechanical properties of the nanocomposites [29-33]. In addition, in the present case, sodium ions in clay can also enhance the gelation effect of Phytigel due to the screening of the electrostatic repulsion between carboxyl groups on Phytigel. **Table 3** shows the mechanical properties of the clay and Phytigel-modified (CPHY-SPC) nanocomposite resin with different nano-clay loadings. For these nanocomposite resins, 15% glycerol was used as a plasticizer. 50% Phytigel was used in a neutral pH to prepare the CPHY-SPC resin. The results show that increasing the nano-clay loading primarily increases the modulus of the CPHY-SPC resin. For 10% clay loading, the Young's modulus

was 2.5 GPa as compared to 1.6GPa for 0% clay loading.

For 5% clay loading, the fracture stress was 74.0MPa as compared to 64.4MPa for 0% clay loading. Further increase in clay loading reduced the fracture stress due to the decreased fracture strain of the specimens. The data in Table 3 also show a steady increase in Young's modulus as well as a continuous decrease in fracture strain with increase in nano clay loading as expected. Clay particle surface is negatively charged, and, at neutral pH, soy protein is also negatively charged. Although sodium ions in clay can screen the electrostatic repulsion, clay particles can also act as defects in the system so as to decrease the fracture strain. The reduction in fracture strain with nano-clay particle addition has been shown in many polymers [24-28].

#### **XRD and TEM Analysis of CPHY-SPC Resin**

Wide-angle XRD was used to evaluate the clay particle dispersion in CPHY-SPC. **Figure 1** shows the XRD patterns of pure Cloisite30B particles as well as CPHY-SPC resins with various amounts of nano-clay particle. As shown in **Figure 1**, the peak obtained for pure clay at around  $2\theta = 4.8^\circ$  disappeared in the CPHY-SPC resins, indicating that the clay particles were exfoliated and dispersed into CPHY-SPC almost completely. The peak at around  $9^\circ$  corresponds to a  $d$  spacing of about 1.2

nm in non-exfoliated (pure) clay. The breakdown of this layered structure of nano clay resulted in the disappearance of this peak in CPHY-SPC resin. Even at the high clay loading of 10%, no clustering can be seen as indicated by the XRD plots. The hydrophilic property of both the clay and the SPC provides the strong interaction between the two phases and prevents clustering of the nanoparticles, thus keeping the stable dispersion of clay nanoparticles in the CPHY-SPC resin.

TEM image is the most direct measurements of the dispersion of nanosized particles. Thin sections of CPHY-SPC specimens with 5% clay were observed using EFTEM. The TEM photomicrograph is shown in **Figure 2** (with a scale bar of 50 nm). As indicated by the TEM image, most of the portion of the clay particles is exfoliated. This confirms the XRD results discussed earlier. The plate like nano-clay particles can take any position in CPHY-SPC as a result of their random distribution in the three-dimensional SPC resin. For those clay particles perpendicular to the specimen surface, single clay platelets were clearly observed.

#### **TGA Analysis of the Modified Resins**

The TGA thermograms of pure Phytigel, pure SPC (without Phytigel), PHY-SPC with 25% Phytigel, and 50% Phytigel are shown in **Figure 3**.

The onset decomposition temperature ( $T_d$ ) for pure SPC resin was 212°C. The  $T_d$  was determined by extrapolating the tangents on two sides of the flexural point on the TGA thermo gram. The incorporation of 30% Phytigel increased the  $T_d$  to 234°C, and PHY-SPC with 50% Phytigel showed a  $T_d$  of 242°C. The incorporation of relatively thermally stable Phytigel in SPC resin leads to an improvement in the thermal stability of the IPN-like PHY-SPC resin. The improvement in thermal stability was directly related to the Phytigel content. The weight loss of the specimen at 120°C can be attributed mainly to the loss of moisture from the specimen. As seen from **Figure 3**, Phytigel does not change the moisture sensitivity of the PHY-SPC significantly, which is consistent with the moisture

absorption results. TGA thermo grams of the CPHY-SPC containing 50% Phytigel and varying clay loadings are shown in **Figure 4**.

Several researchers have reported that clay has the ability to increase the thermal properties of the modified polymer due to the thermal insulation.<sup>42</sup> Our results indicate that nano-clay particles do not have a significant effect on increasing the onset decomposition temperature of CPHY-SPC. The weight fraction remaining (char) at temperatures above 250°C, however, increased with clay loading as would be expected due to the insulating effect of clay particles. This is due to the fact that the clay particles are not affected by temperatures up to 450°C.

**Table 1: Effect of Phytigel Content on the Tensile Properties and Moisture Resistance of Modified SPC Resin**

Phytigel Content (%)	Fracture Stress (MPa)	Fracture Strain (%)	Modulus (MPa)	Toughness (MPa)	Moisture Content (%)
0	13.2 (5.4) <sup>a</sup>	22.4 (5.0)	192 (3.4)	2.5 (7.8)	14.2
5	17.8 (3.5)	22.1 (3.2)	288 (3.5)	3.6 (4.5)	14.4
10	23.3 (4.8)	19.8 (4.1)	367 (5.5)	3.9 (8.8)	14.7
20	26.5 (8.7)	18.3 (3.8)	432 (4.3)	4.3 (7.5)	14.2
30	35.8 (7.7)	15.7 (5.5)	578 (7.6)	4.7 (4.5)	14.1
40	43.5 (5.4)	14.3 (3.4)	612 (6.5)	4.9 (3.8)	13.7
50	48.1 (5.5)	13.7 (4.4)	742 (4.5)	5.4 (3.2)	13.6

NOTE: <sup>a</sup> Values in CV%

**Table 2: Effect of Glycerol Content on the Tensile Properties and Moisture Resistance of PH-SPC Resin**

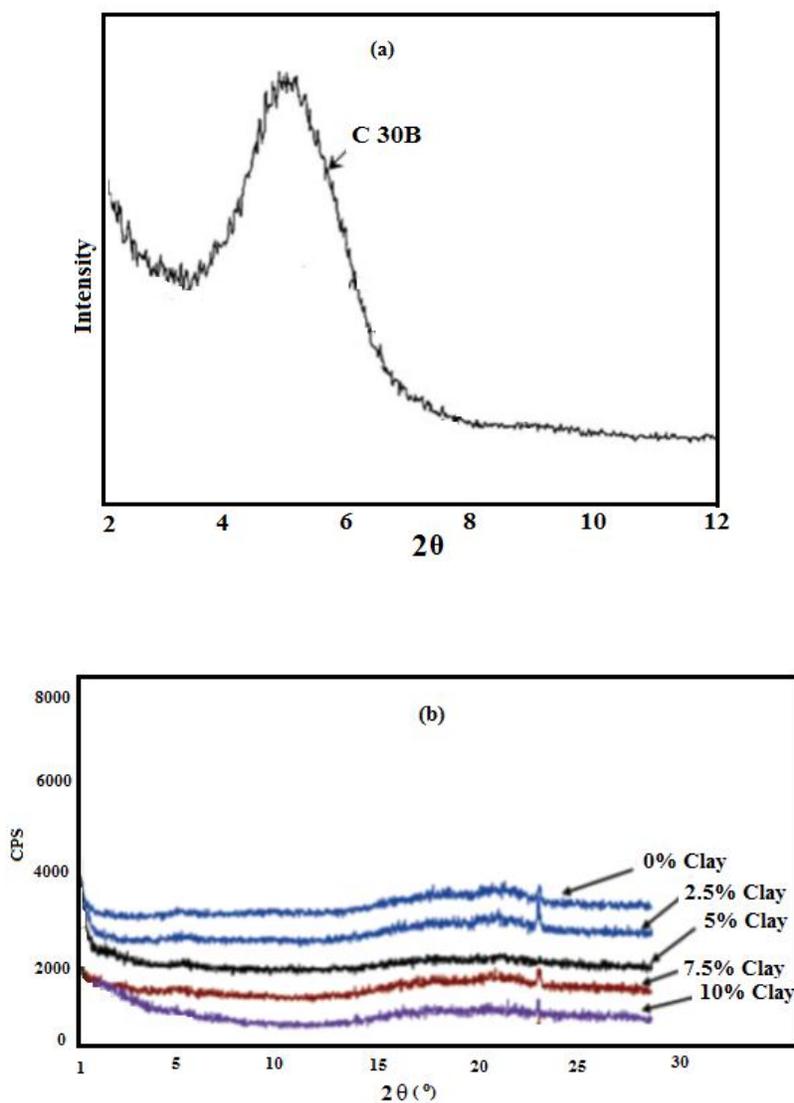
Glycerol (%)	Fracture Stress (MPa)	Fracture Strain (%)	Modulus (MPa)	Moisture Content (%)
5	57.7 (3.3) <sup>a</sup>	5.5 (6.9)	2122 (7.7)	13.7
10	59.8 (4.5)	7.3 (6.4)	2038 (4.8)	14.2
15	62.4 (5.3)	11.2 (5.9)	1367 (3.6)	14.6
20	53.2 (3.8)	14.4 (5.1)	878 (4.2)	14.9

NOTE: <sup>a</sup> Values in CV%

**Table 3: Effect of Nano-Clay Loading on the Tensile Properties and Moisture Resistance of CPHY-SPC Resin**

Clay (%)	Fracture Stress (MPa)	Fracture Strain (%)	Modulus (Mpa)	Moisture Content (%)
0	64.4 (4.2) <sup>a</sup>	10.0 (8.0)	1677 (2.5)	12.1
2.5	68.7 (3.5)	9.5	1978 (5.7)	13.3
5	74.0 (1.2)	9.5	2212 (3.2)	13.7
7.5	71.13 (4.7)	8.9	2345 (2.1)	12.8
10	68.89 (5.8)	7.6	2563 (4.3)	12.9

NOTE: <sup>a</sup>: Values in CV%



**Figure 1: (a) XRD Pattern of Cloisite30B Clay Powder and (b) XRD Pattern of CPHY-SPC Resin With Different Clay Loadings [Y-axis ) %Intensity, X-axis ) Goniometer Angle]**

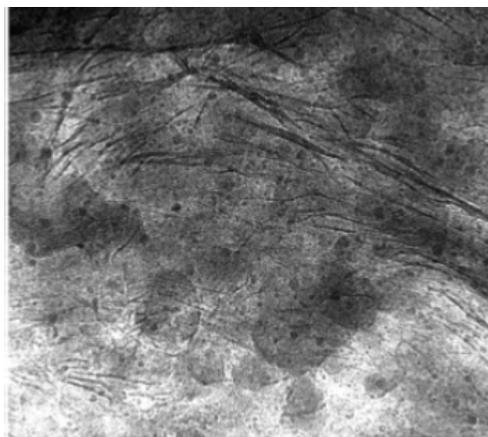


Figure 2: TEM Photomicrograph of CPHY-SPC Nanocomposites With 5% Clay (Scale Bar is 50 nm).

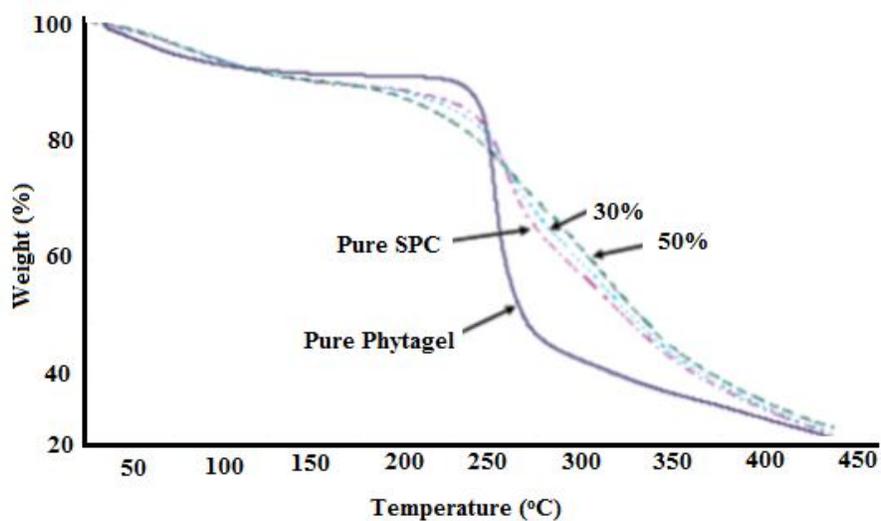


Figure 3: TGA Thermograms of Pure SPC and PH-SPC Resins

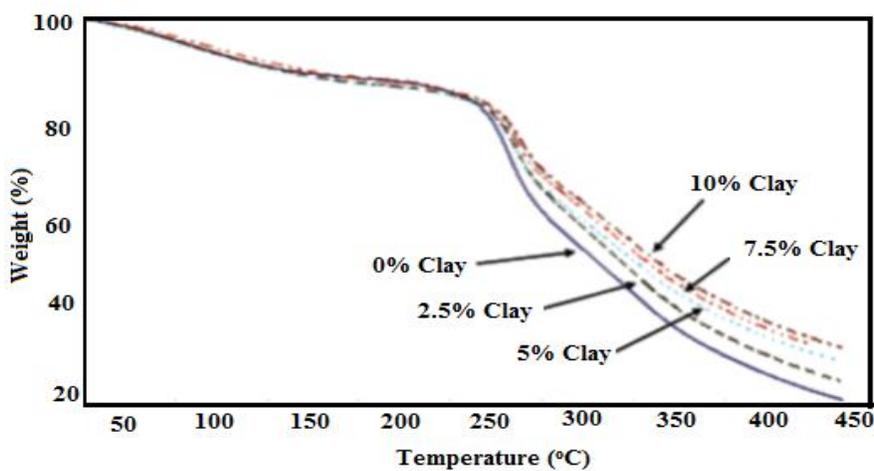


Figure 4: TGA thermograms of CPHY-SPC resins with nano-clayloadings of 0-10%

**CONCLUSION**

Soy protein concentrate (SPC) resin was modified successfully by gellan and nano-clay particles to improve the mechanical and thermal properties and moisture resistance. The tensile properties, moisture resistance, and thermal stability of the modified SPC increased significantly with the addition of C 30Bnano-clay particles and Phytigel. Phytigel increased the modulus and fracture stress of PHY-SPC resin by forming an IPN-like structure. PHY-SPC resin with 50% Phytigel content showed a tensile strength of 48.1MPa and a modulus of 742MPa. The thermal stability as well as moisture resistance was also improved with the addition of Phytigel as compared to the unmodified SPC resin. The SPC resin modified with 50%Phytigel and 5% clay had a modulus of over 2.2GPa and a strength of 74.0MPa. The storage modulus improved with C 30Bnano-clay particles and Phytigel.

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