

STUDIES ON CORN STARCH FILLED POLY (STYRENE-CO-BUTYL ACRYLATE) LATEX REINFORCED POLYESTER NONWOVEN FABRIC COMPOSITES

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Abstract

Poly (styrene-co-butyl acrylate) latex was prepared with a 70:30 weight ratio of styrene to butyl acrylate. Various weight percentages of cornstarch were incorporated into the prepared copolymer latex. Polyester nonwoven fabric reinforced-cornstarch-filled copolymer latex composites were manufactured by the impregnation method. The pickup ratio of latex to fabric was maintained at 3.2:1. The composites' physico-mechanical properties, percent water absorption and percent thickness swelling were studied. The manufactured cornstarch-filled composites were evaluated for their ability to retain their shape after being moulded to the desired shape by measuring the percentage area, shape retention, hardness and resilience. It was observed that the manufactured thermoplastic composite specimens retained or increased their mechanical properties up to 20 wt% cornstarch loading.

Key words:

polyester nonwoven fabric, styrene-co-butyl acrylate latex, starch, composites, tensile behaviour and shape retention

Introduction

Fibre reinforced composite materials¹⁻⁴ consist of fibres of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In this form, both fibres and matrix retain their physical and chemical identities, yet they provide a combination of properties that cannot be achieved with either or the constituents acting alone. The importance and popularity of fibre-polymer matrix composites are due to their unusually high strength and stiffness for a given weight of material. Moreover, altering the composition of a fibre-matrix composition can alter both the properties of strength and stiffness according to requirements. Composites manufactured with a judicious selection of both fibre and matrix find uses in innumerable applied areas. In comparison with thermosetting composites, thermoplastic composites have unlimited shelf life, damage tolerance and impact resistance, and the cost of waste is reduced because they can be recycled.

Short-fibre reinforced polymer composites have gained importance because of some processing advantages and improvements in the mechanical properties of the resulting products. Fibre-related variables that affect these properties include content of fibre, dispersion, orientation, and fibre length⁵⁻⁶. Short staple fibres are less effective as reinforcing material in low-modulus materials than rigid materials^{5, 7-8}. The one way to incorporate longer fibres has been to interlock them into the form of a web, which is called a nonwoven fabric. A nonwoven is a web- or textile-like sheet of fibres. The spun fibres, which may be drawn, are laid down directly onto a belt by needle punching, air laying or carding. Among the various methods of making nonwovens, the needle-punching process has the advantage of producing low-density nonwoven mats with good tensile strength⁹⁻¹⁰, which is essential in making lightweight polymer composites, and helps to incorporate a greater amount of polymer matrix into the composite during manufacture. The most widely used fibres include cellulose, polyamides, polyesters, polypropylene (PP) and polyethylene (PE). In addition to other types of fibre such as glass, aramids, steel and carbon, shredded textile waste has also been used⁷.

The dry-forming technique for nonwovens has several potential advantages over the conventional wet process¹¹, not least with regard to economic investments. However, the strength of the dry-formed nonwoven is insufficient for many purposes. This is due to poor stress transfer through a deformed network, or equivalently, the low degree of inter-fibre coupling. In practice, the generally adopted means of enhancing the strength characteristic is to add a synthetic, polymer-based binder. The binder can be added to the network, for example by spraying latex onto both sides of the dry-formed web, which is the most common technique¹², or by immersing the sheet in an organic solution of a polymer.¹³ A significant improvement in the strength and ductility of the network is obtained with both methods. The use of a latex-based polymer matrix instead of an organic solvent-dissolved polymer is well documented in literature.¹⁴⁻¹⁹ The use of a latex-based matrix for fabricating the nonwoven fabric reinforced composites has several advantages, such as (i) low viscosity (ease of application), (ii) high molecular weight and toughness, (iii) binder variety and versatility and (iv) economy of use.

Starch is a plentiful, inexpensive and renewable material available in a large variety of plant sources, such as grains, tubers, fruits, etc. In many cases, starch is discarded as an unwanted by-product of food processing. Starch is the second largest biopolymer produced on earth, and has been widely used in blends with nonbiodegradable²⁰ and biodegradable²¹ polymers, either to lower the total cost and/or to improve the biodegradability of the material. The starch remains in granular form in the polymer matrix and thus may act as filler material. Its lower specific gravity (1.5), compared with that of inorganic fillers such as clay (specific gravity 2.6) is an important factor for its use as filler. The use of starch in the textile industries, principally in wrap sizing, finishing, thread glazing and printing, has been well studied²².

Extensive research studies have been carried out over the last few years in the composite fabrication using nonwoven fabric and polymer latex.¹⁴⁻¹⁹ Recently, Zhu et al. have studied the effect of polyacrylate on the adhesion to different fibre substrates such as polyester, pure cotton and polyester cotton/blend²³. However, there is little literature on the study of starch-filled polymer latex as a matrix in nonwoven reinforced composites. In this research article, the authors have reported on composites constructed by impregnating the needle-punched polyester nonwoven fabric in poly (styrene-co-butyl acrylate) latex containing different weight ratios of corn starch. The thermoplastic composites thus manufactured have been studied for their physico-mechanical properties and swelling behaviour in water. The composites manufactured were moulded, and the effects of the starch content on the performance of the moulded composites studied by measuring the percentage area shape retention, hardness, resilience and water resistance.

Experimental

Materials

Styrene (St) and butyl-acrylate (BA) monomers of a pure reagent grade were obtained from Aldrich Chemical (USA) and used directly without further purification. Linear alkyl benzene sulphonate (LABS), potassium persulphate (PPS), sodium hydroxide, tapioca starch (used as a protective colloid) and cornstarch (used as filler) were obtained from SD Fine Chem., India.

Uniaxially oriented, polyester-based, needle-punched nonwoven (150 g/m²) fabric with a density of 0.2 g/cc, air permeability of 27-mt³/ m²/ min at 20 WG and a burst strength of 8 kg/cm² was obtained from the local supplier. The fibre used to make the fabric was 3 denier × 64 mm in length.

Preparation of starch-filled poly (styrene-co-butyl acrylate) latex

The copolymerisation of styrene and butyl-acrylate monomer was carried out using conventional emulsion polymerisation.²⁴ 0.5 g of tapioca starch was added to the recipe as a protective colloid during polymerisation. The weight ratio of styrene to butyl acrylate was maintained at 70:30. 50% aqueous cornstarch was prepared, and a calculated amount of cornstarch dispersion was added to the copolymer latex. The ratio of copolymer latex to cornstarch was varied over a range from 100:0 to 50:50 on a dry-to-dry weight basis.

Fabrication of composite

Polyester nonwoven fabric of 150 g/m² was impregnated in a bath containing a cornstarch-filled poly (styrene-co-butyl acrylate) latex-based matrix. The dipped fabric was squeezed in a two-roll squeezer to obtain the desired optimised pickup of latex to fabric (3.2:1). After the desired latex pickup was obtained, the impregnated fabric was dried in an hot air oven at 150°C for 20 min. The dried composites were initially soft, and at this stage they were calendared to improve the surface finish; then, the composites were cooled to ambient temperature to obtain good stiffness. Composites were manufactured with a latex-based matrix filled with different weight ratios of corn starch, viz. 100/0, 90/10, 80/20, 70/30, 60/40 and 50/50 weight-by-weight on a dry-to-dry basis.

Techniques

The solid content of the prepared copolymer latex was determined by a weight loss method. The apparent viscosity of all the prepared copolymer latex was measured using a Ford #4 cup viscometer according to ASTM D 1200-94. The pH of the latex was measured in a Global DPH 500 digital pH meter.

Polyester nonwoven-reinforced poly (styrene-co-butyl acrylate) composites were tested for tensile behaviour, burst strength, stiffness, and stitch tear strength according to test methods SATRA PM2 (Method 1), ASTM D2738, BSI 3748 and IS: 5867-1970 respectively.

Fabricated composites were moulded into a dome shape in a dome former, according to SATRA PM 61. The formed dome was kept in a special compression cage attached to a tensile tester, and the compressive load required to collapse the dome-shaped specimen was recorded as the hardness after the first collapsing load. The specimen after this was removed and subjected to repeated manual collapse. After the completion of the ninth manual collapse, the specimen was again subjected to compressive force, and the load recorded as the hardness after the tenth collapse. This test was repeated after soaking the dome-formed specimens in distilled water for 2 hours. Based on the hardness values obtained both in dry and wet conditions, the area shape retentions of the moulded composites were calculated according to SATRA PM 82. The properties such as percentage resilience and moisture resistance are calculated according to SATRA PM 83.

The water absorption test was carried out according to ASTM D750-95. All the specimens were previously dried in an oven at 50°C for 24 h, and then stored in a desiccator.

Results and discussion

The measured physical properties of starch-filled poly (styrene-co-butyl acrylate) latex such as solid content, viscosity, pH and specific gravity lie within the ranges of 49.3± 0.3%, 24.7± 3 seconds, 7.30-7.45 and 1.03-1.09 respectively. This composition of copolymer latex has been established to achieve maximum impregnation of the matrix into the polyester nonwoven fabric.

Table 1. Mechanical properties of starch-filled poly (styrene-co-butyl acrylate)-polyester nonwoven composites

Composition copolymer/starch, %, dry wt/wt	Tensile strength, MPa	Elongation at break, %	Taber stiffness in units	Burst strength, MPa	Stitch tear strength, N
100/0	11.0	14.46	505	1.68	106
90/10	11.8	17.50	525	1.68	105
80/20	11.0	14.50	506	1.64	104
70/30	10.9	13.25	498	1.48	82
60/40	10.8	12.62	495	1.35	86
50/50	10.7	12.13	490	1.29	71

The effects of cornstarch on the physico-mechanical properties of composites are shown in Table 1. The tensile strength, percentage elongation at break, Taber stiffness, burst strength and stitch tear strength of the composites lie within the ranges of 10.7-11.8 MPa, 12.7-14.64%, 490-535

units, 1.29-1.68 MPa and 71-106 N respectively. All the properties of the composites increased and/or retained up to 20 wt% starch content, compared to the unfilled composites. The composites' tensile strength and percentage elongation at break decreased marginally with the increase in starch content above 20 wt%, compared to the unfilled composites. The decrement observed in tensile strength and percent elongation at break was 2.8% and 16% respectively. Nikolov et al.,²⁴ and I. D. Danjaji et al.,²⁵ have made similar observations with respect to the decreased tensile strength and percentage elongation in maize starch-LDPE and sago starch-LLDPE composites respectively. The starch granule is highly hydrophilic, containing hydroxyl group on its surface, whereas poly (styrene-co-butyl acrylate) latex is basically non-polar. Therefore, in such a system, the formation of strong interfacial bonds like hydrogen bonds is not feasible in the matrix. This will lead to the formation of a discontinuous and non-coherent film. The Taber stiffness, which plays an important role in the application where the composites must stand upright during use, decreased slightly by 3% at 50 wt% starch loading compared to unfilled composites. Burst strength is defined as the hydrostatic pressure required to rupture the composites when deformed in an approximate sphere of 30.5 mm in diameter at a controlled rate of loading. This test becomes important when the composites are subjected to a stress similar to that exerted in the burst strength. With the increase in starch content, the burst strength of the composites decreased, and the observed decrement was 23% at 50% starch loading. The stitch tear strength of the composites indicates the force required to pull a loop of wire through the composite material when the two ends of the loop are first inserted through adjacent holes drilled through the sheet. This test evaluates the composites' ability to hold the stitches when it is being used with other materials to cover the surface to impart good aesthetics. The composites' observed stitch tear strength decreased with the increase in the starch content. A significant decrease in stitch tear strength by 33% for 50% starch filled composition was noticed compared to the unfilled composites. This is because at higher starch contents, filler-filler interactions become more pronounced than filler matrix interaction. As a result, the applied stress is not transferred from the polymer matrix onto rigid starch particles. These factors, plus the fact that no compatibiliser was present in the composites, resulted in poor interfacial adhesion of the starch-filled poly (styrene-co-butyl acrylate) matrix with the polyester nonwoven reinforcement.

Based on the hardness value and the dome height of the moulded composites, the properties such as percentage resilience, percentage moisture resistance and percentage area shape retention in both dry and wet conditions are given in Table 2. The percentage resilience of the moulded composite specimens in dry conditions decreased marginally with the increase in starch content; the values lie within the range of 43-46%. The percentage resilience in wet conditions increased with the increase in the starch content; the values lie within the range of 41% for unfilled composite and 71% for 50 wt% starch-filled composites. The increased percentage resilience of the composites in wet conditions can be attributed to the plasticisation of the starch by water. The percentage area shape retention of the composites decreased with the increase in the starch content in both dry and wet conditions. The reduction lies within the range of 94-78% (dry) and 83-53% (wet). The moisture resistance of the composites decreased from 94-57% with the increase in starch content. This may be due to the hydrophilic nature of starch.

Table 2. Physico-mechanical properties of starch-filled poly (styrene-co-butyl acrylate)-polyester nonwoven moulded composites

Composition copolymer/starch, % dry wt/wt	Hardness after 1 st collapse, Newton		Hardness after 10 th collapse, Newton		Resilience, %		Moisture resistance, %	Area shape retention, %	
	Dry	Wet	Dry	Wet	Dry	Wet		Dry	Wet
100/0	120	118	55	48	46	41	98	94	83
90/10	122	94	52	46	43	48	77	88	82
80/20	120	79	52	42	43	53	65	88	73
70/30	118	74	51	39	43	53	64	87	72
60/40	112	71	49	38	44	53	63	86	68
50/50	90	51	41	36	46	71	57	78	53

The percentage water absorption and thickness swelling of the composites was determined by immersing the specimen in water at room temperature for 2 h, 24 h and 8 days. The results obtained for water absorption and thickness swelling for 2 and 24 h are given in Figures 1 and 2 respectively.

Figure 3 represents the results obtained for water absorption for 24 h and 8 days. It is observed from these figures that the incorporation of starch into the reinforced copolymer latex composite has increased the water absorption and thickness swelling. The rate of water absorption by the composites increased with the increase in the starch content. (Figure 4) The percentage water absorption of the composites was achieved an equilibrium after 7 days of immersion in water at ambient condition.

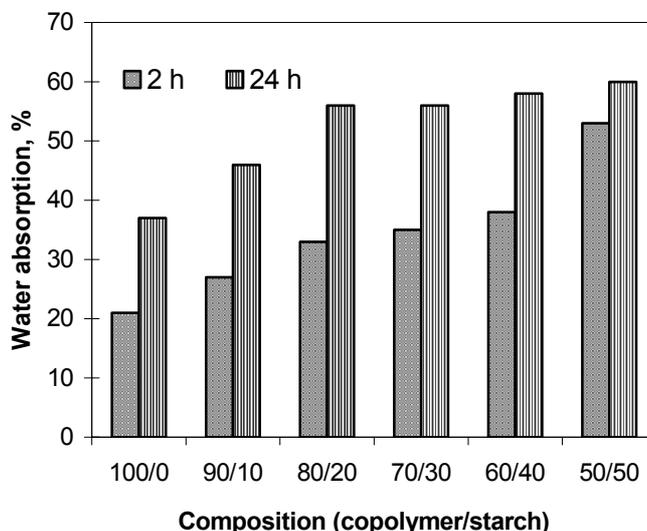


Figure 1. Percentage water absorption of starch-filled poly(styrene-co-butyl acrylate) - polyester nonwoven composites at room temperature

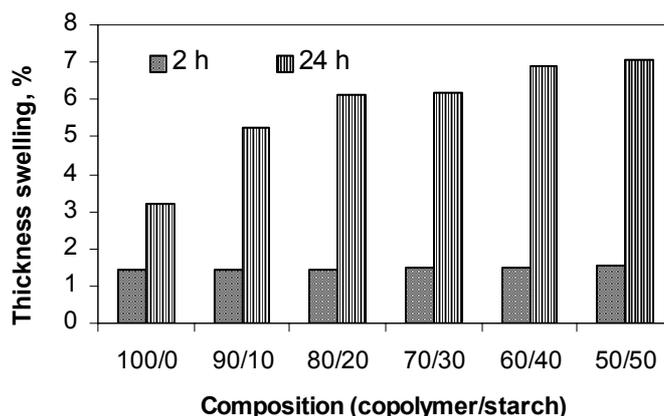


Figure 2. Percentage thickness swelling of starch-filled poly (styrene-co-butyl acrylate) - polyester nonwoven composites at room temperature

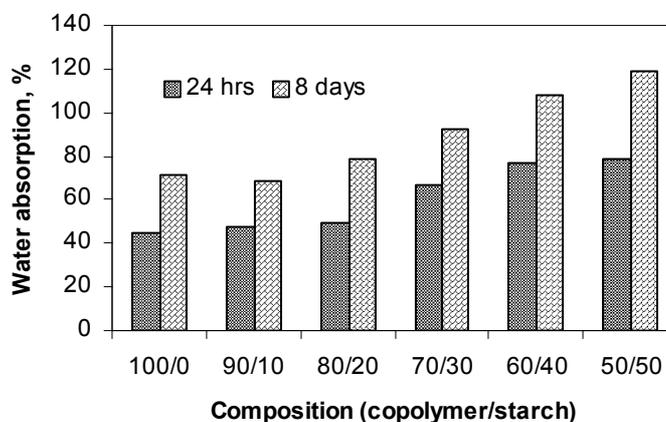


Figure 3. Percentage water absorption of starch-filled poly (styrene-co-butyl acrylate) - polyester nonwoven composites at room temperature for 24 hrs and 8 days

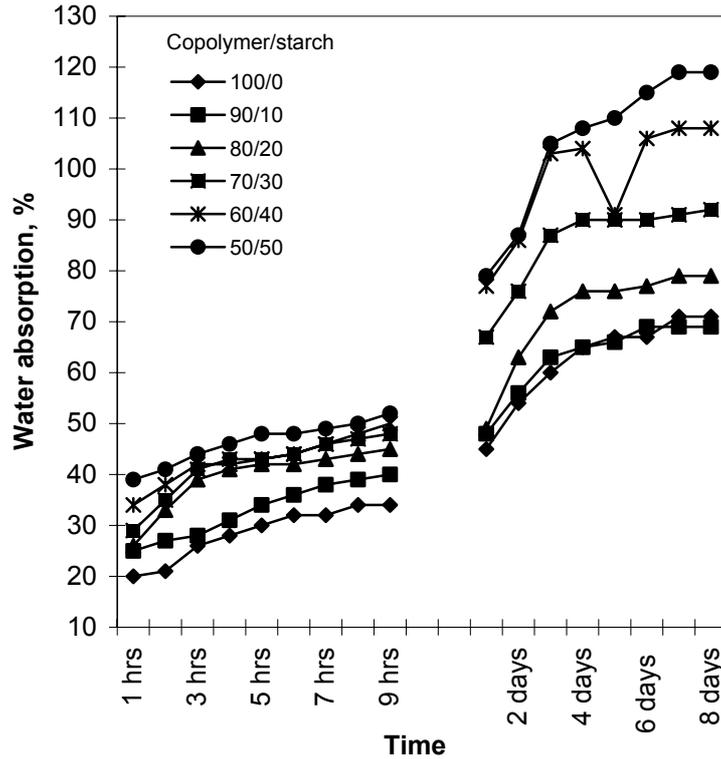


Figure 4. Rate of water absorption of starch-filled poly (styrene-co-butyl acrylate) – polyester nonwoven composites at room temperature

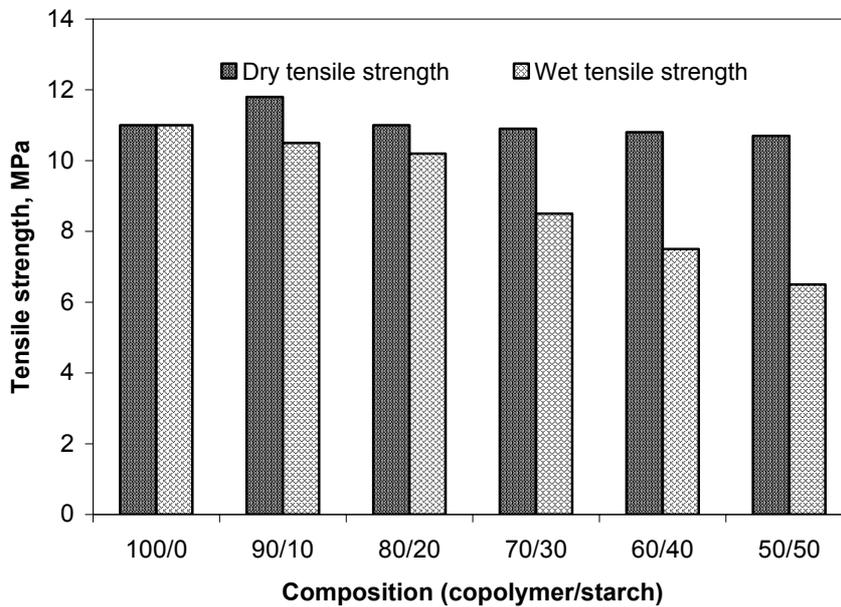


Figure 5. Comparison of dry tensile strength and wet tensile strength of starch-filled poly (styrene-co-butyl acrylate) - polyester nonwoven composites

Figure 5 shows the comparison in the composites' dry and wet tensile strength (completely immersed for 6 h in water) It can be observed that the dry and wet tensile strengths of the unfilled poly (styrene-co-butyl acrylate) based composites are identical in both dry and wet conditions. A drastic reduction in the wet tensile strength of composite specimens was noticed with the increase in starch content, compared to the corresponding dry tensile strength. The measured wet tensile strength of the composites with respect to the time of immersion in water is shown in Figure 6. From the figure, we can observe that a reduction in wet tensile strength was noticed with respect to the time of immersion

in water. The rate of the composites' wet tensile strength decreased with the increase in the starch content. The results indicate that the composite with starch becomes water-sensitive.

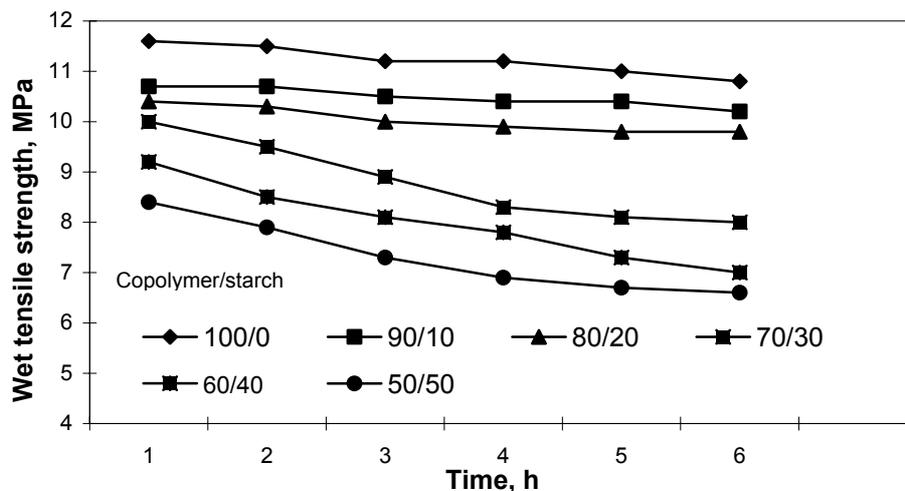


Figure 6. Wet tensile strength vs. time of starch-filled poly (styrene-co-butyl acrylate) - polyester nonwoven composites

Conclusions

In the present study, starch-filled poly (styrene-co-butyl acrylate)-polyester nonwoven composites were manufactured, and the effect of cornstarch content on the physico-mechanical properties (of both sheet and moulded specimens), wet tensile strength, percent water absorption and percent thickness swelling were studied. At 50 wt% starch loading, a marginal decrease in the tensile strength of the composites by 2.8% was noted. The tensile strength, percentage elongation, Taber stiffness, burst strength and stitch tear strength of the composites were almost fully retained at 20 wt% starch loading, as compared to the unfilled composites. The measured properties of the moulded composites such as hardness, percentage resilience, and percentage area shape retention are almost fully retained at 20 wt% starch loading, compared to the unfilled composites. All the properties measured in the wet state decreased with the increase in the starch content, apart from the percentage resilience of the moulded composites.

The practical goal of this work was to incorporate the starch content into the composite's construction, to reduce the demand of petroleum-based inputs and to impart biodegradability partially. From this study, it is evident that cornstarch content can be added up to 20 wt% to manufacture the poly (styrene-co-butyl acrylate)-polyester nonwoven composites.

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