

# A Review on Coating & Lamination in Textiles: Processes and Applications

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**Abstract** Coating and lamination are two functional processes which are used make a proper finishing to the textile material. The coating formulation with different textile grade polymer like PVC, PU, acrylic, PTFE are hugely used to make a textile product with multipurpose way like- waterproof protective clothing, tarpaulin, protective clothing, electrical insulation etc. on the other hand lamination process is used to prepare some important textile products with daily uses in our practical life like- blackout curtains and blinds, and c. In this current work is related to details of lamination theory, various processes, formulations, application, recent developments of the coating and lamination in the textile field.

**Keywords** Coating, Lamination, PVC, PU, Acrylic, Waterproof Protective Clothing, Tarpaulin, Tarpaulin, Lamination Theory, Processes, Formulations, Application, Recent Developments

## 1. Introduction

Coating and laminating are increasingly important techniques for adding value to technical textiles. Coating and lamination enhance and extend the range of functional performance properties of textiles and the use of these techniques is growing rapidly as the applications for technical textiles become more diverse. Cheaper fabric structures may be coated or laminated to provide higher added value to end-users and higher profit margins to manufacturers. The key to success in textile coating and lamination depends upon the application of appropriate technology using modern machinery[1-3]. Machine productivity is important, but flexibility in terms of production speed and the versatility of coating/lamination methods are important factors to consider, as well as a high level of process monitoring, process control and automation to satisfy demanding technical specifications.

## 2. Coating Technology

Coating is a process in which a polymeric layer is applied directly to one or both surfaces of the fabric. The polymer coating must adhere to the textile and a blade or similar aperture controls the thickness of the viscous polymer. The coated fabric is heated and the polymer is cured (that is, polymerized). Where a thick coating is required this may be built up by applying successive coating layers, layer on

layer, Interlayer adhesion must therefore be high[2]. Finally, a thin top layer may be applied for aesthetic or technical enhancement of the coating. Depending upon the end-use requirements, heavy-duty technical textile coatings may be applied at high weight, while other end-uses for high-technology apparel may require coating weights very low. The chemical formulation of the coating, the coating thickness and weight, the number of layers, the form of the technical textile and the nature of any pre-treatment (such as to stabilize the fabric dimensions prior to coating) are of great importance. Traditionally, coating has been applied to woven technical textiles, but increasingly warp-knitted, raschel[3], weft-knitted and nonwoven fabrics must be coated on the same line. The machinery and method of application of the coating formulation must be versatile, minimize tensions on the fabric that may lead to distortion or stretch, and eliminate problems in knitted fabrics such as curling selvages. Scroll opening equipment, weft straightening, tension bars and selvedge uncurlers may thus be fitted[4-6]. The lighter the weight of the technical textile the more prone will be the base fabric for coating to weft line distortion and selvedge curling.

### 2.1. Coating Formulations

The formulation of a coating is complicated, and it can contain a wide range of chemicals depending upon the nature of the polymer, the necessary additives for the specific end use, whether the coating has to be foamed prior to application, and the type of coating machinery to be used. Coatings may be coloured, translucent or opaque, fluorescent, photoluminescent or retro-reflective, according to the end user requirements[7]. Some thermoplastics are used as they allow the material to be used as they allow the material to be used as hot melt adhesive and in some cases for welding techniques. They are used as coating polymers.

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**Table 1.** Some of the useful applications of coating[1,7-9]

Polymer	Typical Products
	Tarpaulins,Coverings, Large tents and architectural uses
	Seat upholstery
Poly Vinyl Chloride (PVC)	PVC polyester-tent covers
	Leather
	Protective clothing ,aprons
	Leisure products,banners,burning
Polyvynilidene Chloride (PVDC)	Blends with acrylics to improve FR in coatings
	Waterproof protective clothing
Polyurethane (PU)	Waterproof/breathable protective coating
	Aircraft life jackets
	Adhesives ,filters used as lacquers for PVC tarpaulins and leather
	Backcoating for upholstery including autoseats
Acrylic	Binders for nonwovens & glass fibres
	Adhesives
	Used as lacquers for tarpaulins
	Backings for carpets & upholstery
Ethylene Vinyl Acetate (EVA)	Wall coverings, exhibition board backing
	Adhesives
Polyolefins,LDPE,HDPE,Polypropylene.	Light weight coverings, tarpaulins (alternative to PVC)
	Sacks
	Bulk bags
	Air bags
	Food, Medical applications
Silicone	Gaskets,seals
	Parachutes
	Woven curtains
	Architectural applications (High abrasion resistance)
Poly Tetra Fluoro Ethylene (PTFE)	Calender belts
	Food & Medical uses
	Gasket, seats
	Carpet backing
	Tyres
	Life rafts
Natural Rubber (NR)	Conveyer belts
	Protective clothing
	Escape chutes
Styrene Butadiene Rubber (SBR)	Carpet backing
	As Natural Rubber
	Oil resistant clothing
Nitrile Rubber (acrylonitrile/butadiene)NBR	Oil seals
	Belts & items handling oily or greasy products
	Resistance to chemicals ,ozone,hydrocarbon,selected oils,solvent
Neoprene Rubber	Neoprene/glass –High temperature application
	Neoprene/polyester –Life rafts,shelter
	Neoprene/nylon –Industrial covers,bellows
EPDM Rubber	Electric insulation
	Items containing gases , e.g. air cushions ,pneumatic springs,bellows
	(Gas barrier)
Butyl Rubber (BR)	Protective clothing – especially for chemicals and acids
	Light weight life jackets
	Life rafts
	Protective clothing
	Aircraft carpet backing
	Aircraft slide/rafts
	Life jackets
	Hovercraft skirts
Polychlororopene rubber. (e.g. Neoprene – DuPont)CR	Flexible gangway bellow (trains)
	Airsprings
	Random covers
	Airbags
	V-belts
	Similar to Neoprene used where coloration is necessary and higher temperature resistance is required . Linear and covers for portable waste reservoir and waste containment ponds.Single ply roofing
Chlorosulphonated polyethylene/rubber (e.g.Hypalon –DuPont)CSM	Hypalon/glass-thermal insulation
	Hypalon/polyester- diapharm
	Hypalon/nylon –roofing
	Hypalon/Kevlar-FR protective clothing
Fluoro elastomer (Viton –DuPont)FKM	Hypalon/neoprene/nylon- inflatable boats
	Specialist protective clothing
	Color resistant
	Low maintenance finish

Modified vinyl acetate	Exellent abrasion resistance
Nitrile	Seals substrate from moisture resistance
Styrene/Acrylic	Tapes
Butadiene	Belting ,tapes,gaskets
Vinididiene	Building products
	Tapes,footwears,gaskets,binder,labels
	Electric paper

**Table 2.** Function of functional properties of different coating composition[8-10]

Functional Properties	Coating chemicals
Stain release	Perfluoro chemical, Polyacrylates, Silicone based products & PVC, Vinylacetate
Soil release	
Water repellent	
Hot oil repellent/resistance	Poly -hexamethylene biguanide hydrochloride-PHMB,Cyclo dextrin Activated carbon based coatings.
Waterproof	
Deodrant/antibacterial clean room fabric finishes,Chemicals	
Chemical odour absorbing	
Chemical protective	Based on Aramide,Teflon, PTFE,Carbon, Neoprene Coating
Breathable coating	Hydrophilic, polyacrilamide based products,Polyurethanes
Thermal resistance & insulating	PVC,Teflon,Carbon coating,Silicon rubber
Heat & corrosive resistant coating	Polytetrafluoroethylene,Perfluorooctanoic acid,Teflon
Stiffness/interlining coating	LDPE/HDPE/PVC
Solvent resistance,abrasion resistance,ageing resistance,ozone resistance	Polyurethane coating
Waterproofing, electrical encapsulation, sealants	Butadiene polyurethane resin

It is important to realize that coating formulations consists of several additives. Amongst these are UV radiation and heat stabilizers, antioxidants, fillers to improve the mechanical properties, fillers for economy, FR chemicals, reinforcement fibers (turning the plastic into a 'Composite'), pigments and other compounds necessary to confer further special properties or to assist with processing[9]. It is necessary to make sure that all the ingredients are compatible with each other.

The formulation of water-proof coating is become very popular in the recent uses of demand and for example; some typical formulations of coatings are as follows;

Table: 3 Formulation of water proof coating using Polyurethane solvent-based resins[11]

Polyurethane (granular form) - 30%., Polyisocyanate crosslinking agent or Melamine formaldehyde resin type and Acid catalyst

**Table 3.** Typical formulation of PVC based coating is as follows[12-13]

PVC	40%
Filler(CaCO <sub>3</sub> )	35%
Primary Plasticiser	Dioctyl phthalate
Secondary Plasticiser	Carboxy Pardtlin Wax
Solvent	Ketone/DMT

### 3. Types of Coating Methods

There are several processes for the application of coating to the textile material depending upon the requirement of end product. Some of these processes are described below:

#### 3.1. Direct Coating

The simplest coating procedure is the direct method, sometimes called the 'floating knife' or knife over air tech-

nique where the fabric is stretched flat to form an even uniform surface and is transported under a stationary doctor blade[13]. As the fiber moves forward, it is scraped by the knife and the polymer resin compound is spread evenly over the surface as per Fig.1 &Fig.2.These show the knife or blade over roller method of direct coating. The amount of polymer applied, the 'add-on'[14] depends on the concentration of dispersion or solution- this is the so-called 'solids content'; other parameters also affect resin add-on as will be seen.

**Uses:** Generally fairly tightly woven fabrics capable of being pulled flat and uniform can be coated by the direct method. Waterproof protective clothing fabric, automotive car seat fabrics, tarpaulins and light weight material for inflatable are produced by the direct method.

#### 3.2. Foamed and Crushed Foam Coating

This method can be used to apply polymer to woven fabrics and knitted fabrics and also to fabric produced from spun yarns or fabrics of a general open construction which cannot generally be direct coated. This is possible because the foam, which is rather like shaving cream, sits on the top of coating. Crushed foam coating increases the no. of fabrics which can be coated ; it also greatly reduces penetration of resin into the fabric , which allows the production of much softer handles and better drape than can generally produced by direct coating[14]. This technique is used for apparel goods, floor coverings, wall coverings ,black-out curtains and curtain linings and filter materials.

#### 3.3. Transfer Coating

The principle of transfer coating is first to spread the polymer on to release paper to form a film and then to laminate this film to the fabric. The process is divided in few

steps like;

- Coat the resin (which will become the top layer) on to the transfer paper and evaporate off the solvent.
- Coat on the second layer, which will become the base layer (and is actually the adhesive which joins the top layer to the fabric).
- Lay the fabric on top of the coating, nip together, evaporate the solvent and crosslink the two layers together.
- Peel the coated fabric off the release paper[15-17].

The main uses of this type of coating technique are the transfer coated polyurethane fabrics is in up-market and the waterproof protective clothing. Other outlets for transfer coated polyurethane include upholstery, luggage, footwear, gloves and waterproof mattress covers. Woven velvet automotive seat fabric is sometimes processed in this way to lock in the pile. Carpets and other articles are also processed using back licking techniques.

### 3.4. Hot Melt Extrusion Coating

This method is used for thermoplastic polymers such as polyurethane, polyolefins and PVC, which are applied by feeding granules of the material into the nip between moving heated rollers. There are two general designs in use, the Zimmer machine, which has two melt rollers the Bema machine, which has three[18-20]. They are smaller version of calenders but differ in that they need a fabric (or paper or a film) as a substrate on which to deposit the film as it is produced. This method can apply resin (in the form of films) to fabric at a faster rate than that can be achieved by transfer coating or direct coating. This process is used to produce light weight coverings or tarpaulins.

### 3.5. Calender Coating

Calenders are primarily used to produce unsupported films of PVC and rubbers from compounded polymer 'dough'. This process can also be adapted to apply freshly produced film to fabric. Calenders consist of a number of massive rollers, sometimes five or more in various configurations, which rotate to crush the 'dough' and smooth it into films of uniform thickness. The thickness of the film is determined by the gap separation of the rollers, but there is usually a limit to the thinness of films which may be produced by this method[21]. The more rollers, film produced is more accurate. Some of the rollers also generates heat, and the material is fabricated into a continuous sheet which can be brought into contact with the fabric to which it adheres.

### 3.6. Rotary Screen Coating

The rotary screen technique which applies compound to a fabric by forcing it through a cylindrical screen, it is used mainly for textile printing. The technique can also be used for coating polymer onto fabric with add-ons; it is claimed from between 5 and 500 g/m<sup>2</sup>. The add-on is controlled by resin viscosity, the mesh of the cylindrical screen; the speed and the pressure of the squeegee bar inside the screen. An array of dots are pushed through the perforated

screen by the squeegee bar inside the screen and by centrifugal force onto the fabric. The fabric moves at the same speed as the rotation of the rotary screen and there is, thus, no frictional contact between the two[22]. When deposited on to the fabric, the resin in the dots flows and merges together to form a continuous coating. The rotary screen method can be used to apply foamed coatings or for foam processing of fabric finishes instead of padding.

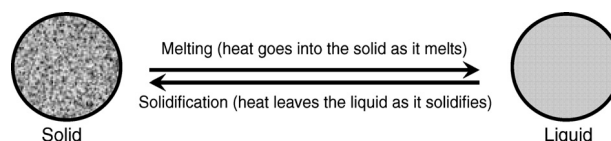
## 4. Recent Development

These are all the conventional process of coating application and formulation but in today's era the requirements of human beings has been totally changed, so research is going on to achieve human needs. Some of such achievements are phase change coatings, conductive coating, anti bacterial coating etc. After all introduction of nanotechnology has changed the thinking. Some of those are discussed below.

### 4.1. Phase Change Materials

Phase change materials (PCM) take advantage of latent heat that can be stored or released from a material over a narrow temperature range[23]. PCM possesses the ability to change their state with a certain temperature range. These materials absorb energy during the heating process as phase change takes place and release energy to the environment in the phase change range during a reverse cooling process. Insulation effect reached by the PCM depends on temperature and time. Recently, the incorporation of PCM in textiles by coating or encapsulation to make thermo-regulated smart textiles is going on.

- Working principle of PCM



**Figure 1.** Change in phase change material with the change in temperature[24]

The PCMs change phases within a temperature range just above and below human skin temperature would be suitable for application in textiles. This interesting property of PCMs would be useful for making protective textiles in all-season. Fiber, fabric and foam with PCMs could store the heat body creates then release it back to body, as it needs. Since the process of phase change is dynamic (Figure 1); therefore the materials are constantly changing from a state to another depending upon level of physical activity of the body and outside temperature. The thermo-regulating characteristic is possible in manmade fiber by adding PCM microcapsules to a polymer solution prior to fiber extrusion. In the process[24], PCM microcapsules are integrated inside the fiber itself. Coating, lamination, finishing, melt spinning, bi-component synthetic fiber extrusion, molding, foam techniques are some of the convenient processes for PCMs' incorporation into the textile matrix.

#### • Coatings using PCM

A coating composition for textiles includes wetted microspheres containing a phase change material dispersed throughout a polymer binder, a surfactant, a dispersant, an antifoam agent and a thickener. Preferred phase change materials include paraffinic hydrocarbons. The microspheres may be microencapsulated. To prepare the coating composition, microspheres containing phase change material are wetted and dispersed in a dispersion[25-26] of water solution containing a surfactant, a dispersant, an antifoam agent and a polymer mixture. The coating would be then applied to a textile substrate. In an alternative embodiment, an extensible fabric would be coated with an extensible binder containing microencapsulated phase change material to form an extensible, coated fabric. PCM could be incorporated into the textiles by coating using polymer such as acrylic, polyurethane, etc, and applied to the fabric. There are various coating processes available such as knife-over-roll, knife-over-air, pad-dry-cure, gravure, dip coating, and transfer coating. This technique is used in space suits, sports-wear, medical applications, shoes and accessories & in automobile textile such as seat cover. Automobile interior applications use paraffin due to their high capacity for heat storage; lack of toxicity, corrosiveness, or hygroscopic properties; low cost; and amenability to mixing to realize the desired temperature range.

#### 4.2. Flame Retardancy

Two types of microcapsules of di-ammonium hydrogen phosphate (DAHP) with respectively polyether- polyurethane shell and polyester-polyurethane shell were evaluated as intumescent flame retardant (FR) in a commercial polyurea coating for textiles. The advantages of this new concept of encapsulated FR agent are to be compatible with a polymeric matrix in order to give a permanent FR effect and to be itself an efficient FR intumescent formulation for many materials. The thermal degradation for the two types of DAHP microcapsules shows characteristics of an intumescent formulation. The reaction to fire of cotton fabrics coated by FR polyurea loaded with neat or microencapsulated DAHP was studied with the cone calorimeter as the fire model. Both types of DAHP microcapsule present in the polyurea coatings on cotton fabric give an efficient FR effect, although the char developed with microcapsules is a little less heat resistant than that developed with the pure DAHP[27]. Coatings containing microcapsules with polyester-polyurethane shells evolve the smallest quantity of smoke and CO.

#### 4.3. Antibacterial Coating

A novel antibacterial coating for cotton fabrics has been developed using core-shell particles that consist of poly (n-butyl acrylate) (PBA) cores and chitosan shells. The spherical particles are prepared via a surfactant-free emulsion copolymerization of n butyl acrylate in an aqueous chitosan solution induced by a small amount of t-butyl hy-

droperoxide. The PBA-chitosan core-shell particles have a narrow particle size distribution with average particle diameter of approximately 300 nm, and display highly positive surface charges. Transmission electron microscopic (TEM) images clearly reveal well-defined core-shell morphology of the particles where PBA cores are coated with chitosan shells. The particle is composed of both the PBA homopolymer and the chitosan-g-PBA copolymer[28]. The cotton fabric is coated with PBA-chitosan particles by using a conventional pad-dry-cure method. The cotton treated with PBA-chitosan particles demonstrates an excellent antibacterial activity with bacterial reductions more than 99%. The presence of apatite-coated TiO<sub>2</sub> shows antibacterial activity in the presence of black light or visible light, suggesting its potential use in reducing the risk of microorganism transmission for textile applications.

#### 4.4. Conductive Coating

Polypropylene (PP) and viscose (VS) textiles were modified by the in situ synthesis of a conducting polypyrrole (PPy) overlayer. To improve adhesion of the conducting layer to the textile surface, a pyrrole-functionalized silane (SP) was synthesized and bonded onto the surface before polypyrrole formation. Moreover, to introduce hydroxyl groups into the surface, PP was pretreated by grafting vinyltrimethoxysilane by means of a radiofrequency plasma discharge. The compromise between the influence of SP and penetration phenomenon (best conductivity after washing:  $wVS-0.2SP/25Py = 3 \times 10^{-5}$  S/square)[29]. In the case of polypropylene the effect of pretreatment with SP is much better than for viscose, and a higher concentration of SP leads to improved fastness of the conductive layer ( $wmPP-0.2SP/25Py = 3 \times 10^{-5}$  S/square;  $wmPP-1SP/25Py = 8 \times 10^{-5}$  S/square), which indicates that the coating promoted by means of SP is more favoured than for viscose.

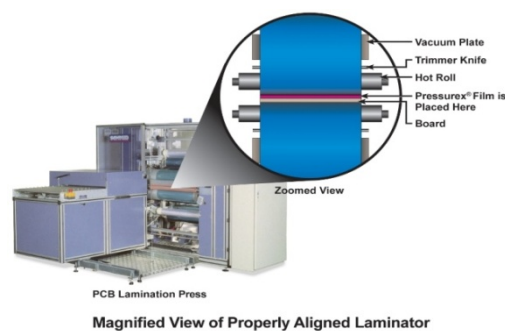


Figure 2. A broad view of different parts of lamination machine[29]

## 5. Lamination

A laminated (or combined) fabric consists of two or more layers, one of which is a textile fabric, bonded closely together by means of an added adhesive, or by the adhesive properties of one or more of the component layers. Conventional laminated technical textiles normally consist of one or more textile substrates that are combined using a pre- pre-

pared polymer film or membrane by using adhesives or by using heat and pressure (Figure 2). Usually the layer in a laminated fabric consists of a polymeric substance; however, in some metalized fabrics the metal is not deposited by chemical deposition but is laminated using an adhesive or by use of an electric arc.

Environmental considerations have generated greater interest in hot -melt adhesives, compared with the older solvent-based adhesives, or the flame lamination technique, in which a flame melts polyurethane foam that, while molten, is pressed in contact with the textile. Adhesion in lamination may be over the whole fabric surface or of the discrete type[1-3]. Here the adhesive is applied as a thermo-fusible resin in the form of a dot coating that imparts greater flexibility and less stiffness to the laminate, factors important in subsequent molding applications.

### 5.1. Lamination Theory in Brief

A new first-order shear deformation theory (FSDT) and sandwich plates has been developed and verified for laminated plates and sandwich plates. Based on the definition of Reissner - Mindlin's plate theory, the average transverse shear strains, which are constant through the thickness, are improved to vary through the thickness. It is assumed that the displacement and in-plane strain fields of FSDT can approximate, in an average sense, those of three-dimensional theory. Relationship between FSDT and three-dimensional theory has been systematically established in the averaged least-square sense. This relationship provides the closed-form recovering relations for three-dimensional variables expressed in terms of FSDT variables as well as the improved transverse shear strains. This makes two main contributions. First an enhanced first-order shear deformation theory (EFSDT) has been developed using an available higher-order plate theory. Second, it is shown that the displacement fields of any higher-order plate theories can be recovered by EFSDT variables. The present approach is applied to an efficient higher-order plate theory[26-27]. Comparisons of deflection and stresses of the laminated plates and sandwich plates using present theory are made with the original FSDT and three-dimensional exact solutions. A refined nonlinear zigzag shear deformation theory of composite laminated plates is presented using a modified mixed variational formulation. The theory accounts for continuous piecewise layer-by-layer linear variation approximation in the thickness direction for the displacements. Moreover, it includes piecewise stress distributions satisfying the continuity conditions at the layer interfaces and the surface conditions. The advantages of this theory are that it recovers the interlaminar stresses, and does not need any shear correction factor used in other first-order theories. To assess this theory, the bending problems of symmetric and anti symmetric cross-ply laminated plates are solved. Some numerical results for the deflection and stresses are compared with their counterparts obtained due to three-dimensional elasticity solution and higher-order laminate theories.

In the classical theory of plates (CPT), it is assumed that plane sections initially normal to the mid surface before deformation remain plane and normal to that surface after deformation. This is the result of neglecting transverse shear strains. However, non-negligible shear deformations occur in thick and moderately thick plates and the theory gives inaccurate results for laminated plates. So, it is obvious that transverse shear deformations have to be taken into account in the analysis. First order shear deformation theory (FSDT) and takes the displacement field as linear variations of mid-plane displacements. In this theory, the relation between the resultant shear forces and the shear strains is affected by the shear correction factors. This method has some advantages due to its simplicity and low computational cost. Some another plate theories, namely, higher order shear deformation theories (HSDT),[29] which include the effect of transverse shear deformations provided a simple higher- order theory which accounts not only for transverse shear strains but also for a parabolic variation of the transverse shear strains through the thickness.

### 5.2. Flame Lamination

Flame lamination can be used to adhere polyurethane foam to a textile material. A web of

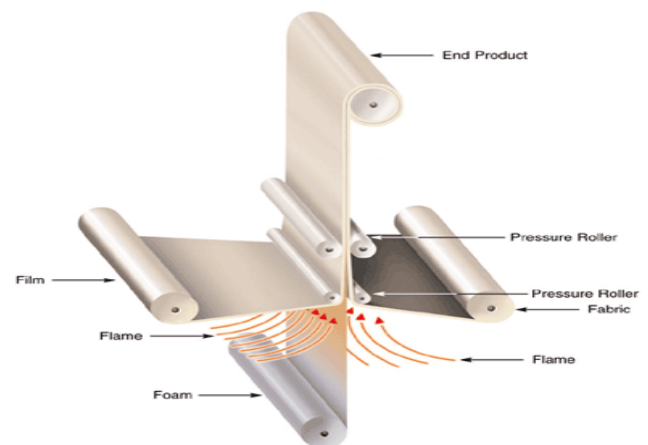


Figure 3. Process of flame lamination[30]

Polyurethane (P.U.) foam from a supply roller is passed over a gas flame at around  $950^{\circ}\text{C}$  and combined with the textile material from a second roller in the first nip of a three-bowl system[30]. The foam-laminated textile material is then passed through the second nip and wound up on a third roller (Figure 3). Three-ply laminates are possible by the addition of a second burner to the machine. The major disadvantage is the high capital cost of equipment-for instance, carbon filter absorbers are needed to clean up the gaseous emissions so that they comply with legislative requirements. Flame lamination has been widely used for automotive fabrics.

### 5.3. Adhesive Lamination-aqueous Based

Adhesive lamination can be used to laminate two fabrics by applying an aqueous-based pressure-sensitive adhesive



by knife-over-roller spreading. Alternatively, the pressure-sensitive adhesive can be spread on a release paper and then transfer coated to the textile material, which can then be combined with a second fabric by bringing these into contact under heat and pressure to remove the water[21]. Typical of the adhesives used are natural and synthetic rubber, styrene-butadiene resins (SBRs), polyvinyl alcohol and acrylic polymers (Figure 4).

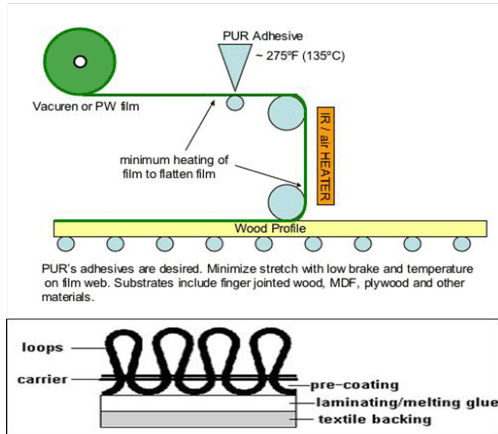


Figure 4. Process of adhesive lamination[21]

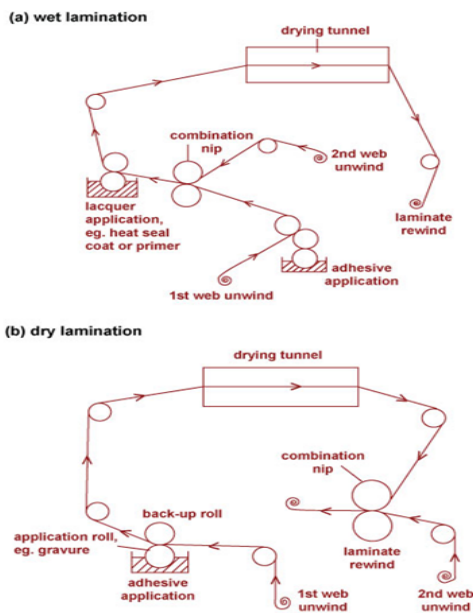


Figure 5. Process of adhesive lamination-solvent-based[31]

A second method of applying aqueous-based adhesives using hot -melt polymers is to use rotary screen-printing. The water is evaporated using infra-red heating, the polymer is melted and a second layer of material brought into contact with it to create bonding. Aqueous-based adhesives such as ethylene vinyl acetate, polyethylene, polyamide, polyesters and polyurethane can be used, and the adhesives may be foamed, applied in a specific pattern, and spread by a second blade after the print head[24-25]. A softer handle with greater breathability can be obtained using this technique, but heat-sensitive textile materials may be difficult to control. Typical uses of this type of technique products include blackout curtains and blinds, and disposable hospital ap-

parel.

5.4. Adhesive Lamination-solvent-based

Solvent-based adhesives can be used to laminate micro-porous membranes to textile fabrics to provide a barrier against liquids (for use in hospital theatre gowns and to protect mattresses, for instance)[31]. Solvent-based polyurethane that cures in the presence of moisture is sprayed on the fabric and the membrane is nipped against the adhesive surface (Figure 5). Then the two are held together while cross-linking takes place to form the necessary bonding. Engraved roller or screen-printing techniques may also apply solvent-based adhesives.

5.5. Heat Lamination

Heat lamination using a coating or hot -melt adhesive supplied as a solid, or slit film net or web can be carried out on the surface of a heated central drum (180-250[degrees]C) where the materials are held together as a two-ply composite under a tensioned continuous pressure blanket[7]. Flatbed laminating machines can also be used, but the method is unsuitable for heat-sensitive fabrics (Figure 6). Heat lamination has been widely used for heat-sensitive fabrics.

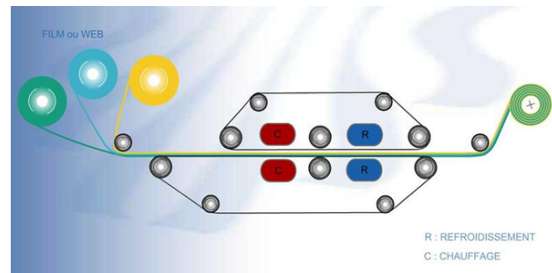


Figure 6. Process of heat lamination[5]

5.6. Hot -melt Adhesives

Hot -melt adhesives are thermoplastic and can be melted or softened by heat. When spread on the fabric in the hot state, lamination with another fabric can occur on re-solidification as the coating cools down. A variety of methods can be used with hot -melt adhesives. Slot die extrusion allows high viscosity hot -melt adhesives to be extruded as a continuous film directly on all types of textiles. Mixing the ho-melt adhesive with air inside. Alternatively, roller and calender hot -melt coating and laminating may be used. Hot -melt adhesive, ground down to 60-200 [mu]m particle size can be applied from an engraved roller (at 250°C or above) in a predetermined pattern to a heat-stable fabric (Figure 7). Then a second fabric or film is brought into contact while the adhesive is still molten[23]. In another application method, adhesive is applied from a hopper placed above a card-wire covered roller that holds the powder until this is released by a vibrating wire brush. This scatter-coating method applies the powder in a discontinuous random pattern. The scatter-coated fabric may be passed into a flatbed laminator. This contains two driven belts (top and bottom) with a heating section, in which the adhesive is melted, and a cooling section, to solidify the adhesive while

the laminate is still under pressure[25].

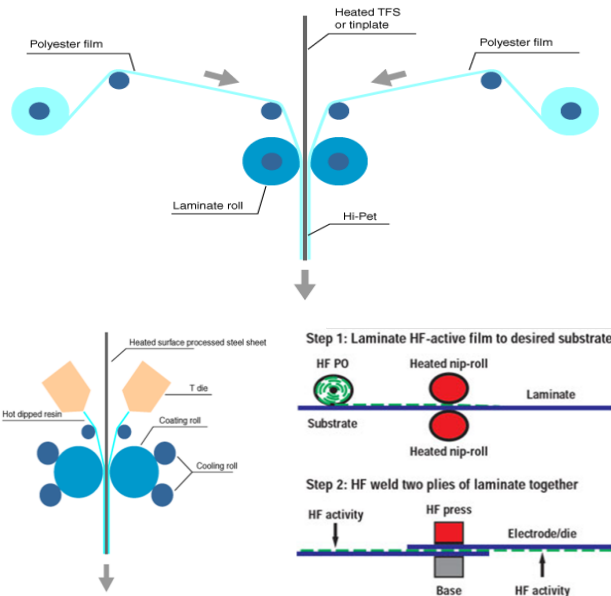


Figure 7. Hot melt laminating principle in case of PET yarn[25,27]

5.7. Film Lamination

Laminate film is generally categorized into these five categories (Figure 8):

- Standard thermal laminating films
- Low-temperature thermal laminating films
- Heat-set (or heat-assisted) laminating films
- Pressure-sensitive films
- Liquid laminates[5]

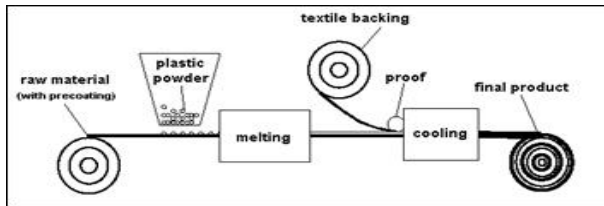


Figure 8. Working principle of film laminating machine[8]

6. Recent Developments in Lamination Technique

Table 4. Comparison between the continuous and discontinuous lamination techniques

Continuous Lamination (On- / Offline) [20-24]	Discontinuous Lamination (Definite-Length) [21,22]
For rubber and plastic parts	For rubber and plastic extrusion
Max. lamination. speed : 15 m/min; (depending on compound)	Max. lamination. speed : 30 m/min; (depending on compound)
Lamination of most available tapes: heat-bond / pressure sensitive	Lamination of most available tapes: heat-bond / pressure sensitive
Combination equipment for heat-bond and pressure sensitive tapes	Combination equipment for heat-bond and
Precise tape position	Pressure sensitive tapes
Controlled lamination force	Precise tape position
Controlled tape stretch	Controlled lamination force
Defined tape tension	Controlled tape stretch
Controlled temperatures	Defined tape tension
Reliable controlled process	Controlled temperatures
Control of the process parameter	Reliable controlled process
Manual - semiautomatic - automatic – robot-lamination	Interface for external data log

There are several modern developments is going on through in the field of coating and lamination technology with the aim of improvements of this emerging area; for example a few of them has been discussed in below;

6.1. Manufacture of 3D Structures by Cold Low Pressure Lamination of Ceramic Green Tapes

3D multilayer devices were generated by Laminated Object Manufacturing (LOM), a well-known rapid-prototyping technology. Divergent from this method, commercial ceramic green tapes were used which were laminated by Cold Low Pressure Lamination (CLPL). In contrast to thermo-compression, which works at pressures and elevated temperatures, CLPL allows to join particularly fine, complex structures with cavities or undercuts, because no mass flow occurs. This technique is based on gluing the adjacent tapes by means of an adhesive film at room temperature under a low pressure[16]. After binder burnout and sintering the ceramic laminate has a homogenous and dense microstructure free of interfaces. This modified LOM technique is particularly suitable for the production of Micro Electro Mechanical Systems (MEMS).

6.2. Embedding Capacitors and Resistors into Printed Circuit Boards Using a Sequential Lamination Technique

Embedding capacitors and resistors into printed circuit boards (PCBs) offers many benefits over surface mount technology (SMT) and through-hole packaging (PTH). These benefits include improvements in electrical performance and reliability, and potential cost reduction. Embedded devices also enable signal integrity at speeds over 1 GHz. Also, replacement of surface mounted discrete passives with an embedded passives layer allows for tighter component spacing, fewer holes and a larger routing area[32]. All these are essential for board miniaturization. However, the goals of reliability improvement (Table 4), space conservation, performance enhancement and solder joint reduction by using embedded passives can only be realized if the PCB fabricator can produce high quality boards in a practical production environment in a timely manner.



### 6.3. High-performance Polymer Photovoltaic Devices with Inverted Structure Prepared by Thermal Lamination

Use of a lamination process for the introduction of Au electrode, instead of conventional metal evaporation, improved the power conversion efficiency (PCE) of inverted-structure photovoltaic devices from 1.6% to 2.6% based on a bulk hetero junction of poly(3-hexylthiophene) (P3HT) and (6,6)-phenyl C<sub>61</sub> butyric acid methyl ester (PCBM). X-ray photoelectron spectroscopy indicated that a thin layer of P3HT is spontaneously formed at the air/polymer blend layer interface during the spin-coating process. It is suggested that the vacuum-evaporated gold could destroy the surface-segregated thin layer of P3HT[10,25], while the lamination process preserves the surface structure working as an electron-blocking layer. The insertion of a PEDOT:PSS layer, between the metal electrode and polymer layer, in the lamination process further improved the PCE to 3.3% with a short-circuit current density of 9.94 mA cm<sup>-2</sup>, an open-circuit voltage of 0.60 V, and a fill factor of 55% under AM1.5 100 mW cm<sup>-2</sup> irradiation.

### 6.4. Processing of an Aqueous Tape Casting of Mesocarbon Microbeads for High-performance Carbonaceous Laminations

Tape casting is a traditional method for the manufacture of ceramic laminations. In this study, aqueous tape casting was adopted to obtain high-performance carbonaceous laminations with homogeneous density and high strength. For the preparation of a stable and homogeneous slurry of mesocarbon microbeads, the research focuses on the rheological behavior of slurries consisting of a solvent and additives such as a binder, plasticizer and dispersant. After three to five slips of casting tape laminated together under 40 MPa at 85 °C and sinter heated to 1400 °C for 1 h at a given heating ratio, carbonized laminations are obtained with an average density of 1.66 g/cm<sup>3</sup>, a bending strength of 82.76 MPa and an electrical conductivity of 169.2 S/cm. During sintering of green laminations, the additives are pyrolyzed at 500 °C to form amorphous carbon[28], which reduces the electrical conductivity and the mechanical strength of the carbonized laminations. However, by controlling the total additive content of the slurries, the influence of the additives can be reduced to a minimum.

### 6.5. Novel Cold Chemical Lamination Bonding Technique—A simple LTCC Thermistor-based Flow Sensor

Lamination is a quality determining processing step in fabrication of LTCC multilayer devices for packaging, fluidic microsystems, and sensors. DM765E distilled water dilution was applied, using a paint brush, on a top surface of a green ceramic piece. The gluing process was carried out at low pressure about 15MPa at room temperature, achieving good bonding quality. The method is dedicated to water-based slurries. The common LTCC tape bonding method is thermo-compression. The tapes are joined at high temperature, up to 80°C, and pressures, up to 30 MPa, for 2–15 min. The temperature softens the tapes, facilitating pressure bonding. This method has several advantages: thermo-compression gives good encapsulation of the final device, strong bonding[25, 26], and allows the resulting structure to have more than 40 layers. However, there is one important problem: high pressure and temperature cause deformation of the manufactured structure. The main advantage of this technique is that the bond is made at room temperature and low pressure, about 5 MPa, thereby decreasing the deformation of the chambers and channels. However, it also has disadvantages: the increase of pressure in the chamber during firing destroys modules with closed chambers, and the laminated stack may crack during the firing process. The method is therefore best used for making open chambers and channels.

## 7. Lamination Faults

There some faults can be usually appears in the laminated products during the process. This faults can be removed or partially decreased by a proper m/c setting, controlling different parameters like; heating, temperature, degree of adhesion limit etc. Few of the lamination faults which generally frequently appears in lamination process have been discussed in below (Table 5);

## 8. Conclusions

The coating and lamination gives a powerful tool for the advancement of textile technology. It provides the opportunities to produce the special fabrics like water-proof resistant tarpaulins, coverings, large tents and architectural uses, backcoating for upholstery including autoseats, Food, Medical applications, parachutes, Woven curtains, for heat-sensitive fabrics, automotive fabrics, disposable hospital apparel etc. the recent developments also enhanced the lamination and coating technique into state-of-art process of the future in textile field.

**Table 5.** List of some common lamination fault in textile finishing[11,12,18]

Faults name	Reasons	Remedies
Bubbles	Improper roller nip pressure	Proper roller surface mapping
Particles	Poor mixing of laminating pest	Excellent grinding of the materials in the laminating pest
Age cracks	In stability of the laminating pest/solution/adhesives	Advanced camera technology for highest contrast
Misalignment of edges	Luck of proper supervision to the process	Easy integration into production lines
Laminating faults	Quick process, less time	Networking for further evaluation

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