Reusing Adhesive Tapes from Electrospun Polymer Fibers

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The University of Akron

Reusable Adhesive Tapes from Electrospun Polymer Fibers

Honors Research Project

By

Vishal Chaurasia

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05/04/2015
ABSTRACT

Many emerging applications demand an adhesive that has reusable properties. The adhesive must exhibit high adhesion strength to various surfaces and be able to be removed easily and then reapplied with minimal to no loss in adhesion strength. This work aims to tackle this problem by creating an adhesive tape fabricated by electrospinning polymer solutions onto a substrate. Electrospun adhesive nano/micro fibers have the ability to display the reusable characteristics desired. Several adhesive custom formulations were first developed and optimized for electrospinning. Then these formulations were successfully electrospun on to various substrates after much fine tuning of electrospinning parameters. The resulting adhesive tapes had higher shear strengths than peel strengths and were reusable with minimal loss in adhesion.
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INTRODUCTION

Adhesives play a significant role in a plethora of products and applications in today’s world. From the industrial end to the consumer end, adhesives have found their way into functional roles without which many technologies would fail. Adhesion research continues to examine fundamental adhesion mechanisms and to explore ways in which we can produce superior synthetic adhesives. A more recently emerging desirable adhesive property is reusability. In many applications, it would be desirable to have an adhesive that can be applied to a surface, adhere strongly, and then be easily removed. This cycle should be able to repeat without significant loss in adhesion strength. An application example could be in robotic arms or grippers. A reusable adhesive pad attached to the gripper can allow continuous cycles of gripping and releasing objects. An everyday application can include packaging tape or wall hooks. A strong packaging tape that can be easily removed and reused without damaging the cardboard box surface would be desirable. Wall hooks that use this type of adhesive technology would have the ability to be repositioned, reused, and not damage the wall surface.

We can aim to engineer an adhesive tape that can satisfy the above application requirements of reusability. This requirement can translate to an adhesive design criteria of high shear strength and simultaneous low peel strength. The research is broken into two stages to approach this problem and find an engineering solution. The first stage requires development of an adhesive polymer solution. The second stage requires coating of the solution onto a substrate via electrospinning. Hence we are deriving a solution to the problem from a material stand point and a morphological standpoint.
BACKGROUND AND LITERATURE REVIEW

Mechanisms of Adhesion

In this section we discuss broadly the different categories of adhesives and bonding mechanisms. Adhesion refers to the tendency of dissimilar particles or surfaces to cling to one another. The IUPAC broadly defines adhesion as the “process of attachment of a substance to the surface of another substance.” Currently there is no single unifying overarching principle that can explain adhesion phenomenon in all domains. In general, the mechanism of adhesion can be divided into 5 basic categories which are discussed below: 1. Mechanical adhesion 2. Chemical Adhesion 3. Dispersive Adhesion 4. Electrostatic adhesion 5. Diffusive Adhesion (Wikipedia Contributors, 2015).

Mechanical Adhesion

Mechanical adhesion occurs when the materials can mechanically interlock in some fashion. This can occur if a continuous solid adhesive material fills the voids or pores of another material. We can see this phenomena from Figure 1 Mechanical interlocking mechanism.

Figure 1 Mechanical interlocking mechanism (Mattson, 2014)
The adhesive penetrates the porous substrate and thus locks itself mechanically. Mechanical interlocking can also be interpreted at larger macroscopic scales. For example the brand name material Velcro works on the basis of hooks and loops. When a mesh of hooks are pressed against the mesh of loops, they mechanically interlock and in a sense adhere.

**Chemical Adhesion**

Chemical adhesion occurs when a chemical reaction occurs between the two materials, specifically at the surface interface. The two materials could form a compound at the join. The chemical bond can be a primary bond such as ionic or covalent or it can be a hydrogen bond. The primary bonds are very strong and thus can create strong adhesion however it is important to note that these types of chemical interactions are effective over only atomic length scales. Therefore to create a chemical bond the surfaces need to be brought in contact at atomic length scales for the reaction to proceed. In addition, these bonds are usually brittle because the surfaces are required to be kept close together (Wikipedia Contributors, 2015).

Figure 2 Chemical Adhesion (Mattson, 2014)
**Dispersive Adhesion**

Dispersive adhesion, also referred to as adsorptive adhesion, involves the intermolecular weak interactions between molecules. These weak interactions stem from van der Waals forces which are responsible for holding together the two materials. In molecules, whether simple or complex, regions of partial charges can develop and thus there can be polarity with respect to average charge density. These positive and negative poles can be permanent which then are called Keesom forces or they can be momentary which are then called London forces. London forces can exist with almost any molecule because they arise due to the momentary concentration of electrons in a certain spatial region of the molecule. A temporary high concentration of electrons creates a negative partial charge in that region which is then attracted to a positive partial charge region of another molecule. This attraction in turn can give rise to adhesion between surfaces. It is important to note that these weak van der Waals interactions occur in the atomic length scales. At distances larger than nanometers apart, the van der Waals forces are basically negligible and thus will not contribute to the adhesion of two surfaces. The van der Waals force between two molecules is relatively very weak for adhesion however if two surfaces have superb intimate contact at the nano scale then the van der Waals interactions can sum up over the area to give excellent macroscopic adhesion. These types of systems are excellent candidates for “dry adhesives.” These van der Waals interactions are reversible and thus the adhesion mechanism is too.

**Electrostatic Adhesion**

Electrostatic adhesion occurs when differences in electro-negativities create an adhesive force. This force arises from the transfer of electrons across the interface which creates
oppositely charged surfaces which attract to each other. This is related to the electric double layer theory. Some simple examples of this phenomena are the adhesion of plastic packaging on hands, paper on CDs, and paints and coating for metals.

Diffusive Adhesion

In diffusive adhesion, the polymer chains at the interface diffuse and thus merge the two materials at the join. In order for this to occur the molecules of both materials should be readily mobile and soluble in each other. The polymer chains may be bonded to the surface at one end and free at the other end. The free ends of the chains can then diffuse with each other and create stronger interactions, especially from the entangling of the polymer chains. The degree of entanglement can be quite sensitive to independent variables such as contact time and pressure, temperature, and chemical properties. The flexibility of the polymer chains at the surface also has a large effect on the amount of diffusive adhesion that can occur. The more flexible the chain is, the more interdiffusion can occur increasing the bond’s strength.
Electrospinning Technology

Electrospinning is recognized as an efficient technique to create polymer nanofibers. With a relatively simple equipment set-up, it is possible to fabricate continuous polymer fibers in the diameter range of a few nanometers to microns. During the electrospinning process, an electrified jet of viscoelastic polymeric material undergoes uniaxial stretching, and thus a significant reduction in diameter, and gets deposited as continuous fibers on a collector. This drawing force arises in the presence of a high voltage electric field between the polymer solution and the collector. A solid fiber can be generated as the electrified jet is continuously stretched due to the electrostatic repulsions between the surface charges and the evaporation of solvent (Li & Xia, 2004) from the solution. The thinning of the fibers can also be due to the bending instabilities associated with the electrified jet. A very basic electrospinning set up can be seen the figure below.
The basic electrospinning setup consists of a syringe with a needle, a high voltage power supply, and a collector. The syringe holds the polymer solution and the flow rate of the solution can be controlled by a syringe pump or other methods. The needle through which the polymer solution is extruded is electrified with a high voltage power supply, usually direct current but alternating current has also been used, which also electrifies the liquid jet. The jet experiences two major types of electrostatic forces which are the electrostatic repulsion forces and the Coulombic forces. The repulsion forces arise from the repulsion between the surface charges and the Coulombic forces arise from the external electric field. With these forces and interactions, the solution forms a conical shape called the Taylor cone just at the exit of the needle nozzle. The jet experiences bending instabilities and a whipping action which generates very high elongation stresses and thus a reduction in diameter. The continuous fibers generated are then simply deposited on to the collector.
The final product achieved with the simple setup shown above consists of a non-woven randomly oriented nanofiber mat.

**Processing Parameters of Electrospinning**

The final properties of the electro spun fibers are greatly impacted by the several processing parameters. Therefore to control various properties, such as surface morphology, the processing parameters can be adjusted accordingly. Prior literature and experimental work by many researchers have shown certain trends regarding electrospinning parameters and fiber properties. The key parameters, especially those that significantly impact fiber diameter, are discussed below.

*Solution Concentration / Solution Viscosity*

For a given thermoplastic polymer material, creating solutions of different concentrations will significantly impact the electrospun fiber diameters. A basic solution will consist of a polymer and a solvent and the final concentration of the solution can be altered by changing the ratio of polymer to solvent. Since solvents are small molecules they will have viscosities with magnitudes similar to that of water. The polymers will have viscosities magnitudes higher, mostly depending on their molecular weight. Therefore, quite obviously, a solution with high concentration of polymer will be more viscous than a solution with low concentration of polymer. From numerous prior experiments, it is noted that there is a range of viscosities that the solution must fall in in order to be successfully electrospun. Therefore, different polymers will require different solution concentrations to create a solution that falls within the acceptable viscosity range. If the final solution viscosity is too high then fibers may fail to form because the cohesiveness of the solution
dominates and causes flow problems. If the final solution viscosity is too low then fibers may fail to form and instead droplets will form and electrospraying will occur. In general, a higher solution viscosity results in larger electrospun diameters.

**Applied DC Voltage**

The magnitude of the DC voltage applied to the polymer solution will affect the behavior of the jet significantly. The jet stability and thus fiber morphology are affected by varying the voltage. An increase in voltage increases the electric field potential and thus the electrostatic force on the polymer jet. Therefore, a higher voltage causes higher elongational stresses and thus creates smaller fiber diameters. However, if the voltage is too high then bead formation may occur instead of a continuous fiber.

**Flow Rate**

The flow rate of the polymer solution can be controlled via a syringe pump. Typically the flow rates are on the magnitudes of ml/hour and precise control is necessary for consistent fiber properties. Quite intuitively, increasing the flow rate will increase the fiber diameter. It is important to note that depending on the flow rate you must choose an appropriate size nozzle. In many cases that means you want an appropriate gauge syringe needle to produce successful electrospinning results.

**Solvent**

The specific type of solvent used to dissolve the polymer will play a role in the process. First and foremost, the solvent must be a “good” solvent for that type of polymer, which means that it can dissolve the polymer thoroughly and create a homogenous solution. The evaporation rate, or volatility, of the solvent affects the morphology of the fibers.
Sometimes co-solvent techniques can be used to control morphology wherein you alter the ratio of the co-solvents to produce fibers with different characteristics. The conductivity of the polymer solution also plays a vital role. Different solvents inherently have different dielectric properties and thus this is an important parameter to keep in mind. Sometimes conductive agents such as salts can be added to the solution to increase the conductivity. Increasing the conductivity increases the ability of the jet to carry charges which then allows higher elongation forces. Therefore, increased conductivity decreases fiber diameter.

**Collector Configuration**
Collectors can be made in many different configurations. You can divide them into static and dynamic collectors. For dynamic collectors, such as the rotating drum collector, the angular rotational speed will affect the fiber morphology. In fact the velocity of the surface is the variable that directly plays a role. The velocity, or take up velocity, is a function of angular speed and drum diameter. It has been shown that increasing the take up velocity can decrease the fiber diameter. In addition, the rotating drum collector also has the ability to create aligned fibers. The fibers align in the circumferential direction of the drum (Najem, Wong, & Ji, 2014).

**Nozzle to Collector Distance**
No matter which collector configuration is used, there will be a distance between the nozzle tip and the collector surface. This parameter directly impacts the fiber deposition time, evaporation rate, and the whipping instability interval. These variables all in turn affect the fiber diameter. Increasing the gap distance will decrease the fiber diameter. This occurs
mainly because the fiber undergoes elongation for a longer amount of time. It is important to note that an inappropriate gap distance may not allow fibers to deposit properly at all. For example, a system with a low volatility solvent needs a larger gap distance for evaporation to finish. Otherwise, the fiber appearing solution will “splash” onto the collector surface while depositing and will then lose its fiber shape completely.

**Thermoset Polyurethanes**

Polyurethanes are considered one of the most versatile synthetic polymers. They can be formulated for applications in elastomers, coatings, adhesives, foams, sealants, and more. By altering the chemistry and the building blocks of polyurethanes you can engineer a final product with desirable properties for any specific application.

**Basic Chemistry**

According to the Alliance for the Polyurethanes Industry (API), “Polyurethanes are formed when a polyol reacts with a diisocyanate or a polymeric isocyanate when there are suitable catalysts and additives present.” In this thermosetting material, the bonds that are formed are chemical bonds and thus irreversible meaning they cannot be continuously melted and reshaped like conventional thermoplastic materials. Many of the raw components, such as the isocyanates and polyols, are in liquid form and once the reaction proceeds they form a cured polyurethane cross-linked network. The basic reaction to make a polyurethane is shown below.

\[
\text{isocyanate (component } A) + \text{polyol (component } B) \rightarrow \text{polyurethane + heat}
\]
We can see that the reaction is a simple addition reaction. Note that in industry it is very common to denote the isocyanate as component A and the polyol as component B. This reaction is also exothermic and hence releases heat as a product. In industrial large scale operations, controlling this internal heat generation can be a challenge but is vital for high quality results.

The reason polyurethane products can be so versatile is because there is a broad variety of isocyanates and polyols to choose from. The polyols can have two or more reactive hydroxyl groups per molecule such as diols, triols, and polyols; The same goes with isocyanates. An example reaction is shown in the figure below (CIEC Promoting Science, 2013).

\[
nO=\text{C}=N-R^1-N=\text{C}=O \quad + \quad n\text{HO-}R^2\text{-OH} \rightarrow \left[\text{C}-\text{N}-R^1-N-\text{C}-\text{O}-R^2\text{-O}\right]_n
\]

Figure 6 Simple Polyurethane Reaction

In the figure above the diisocyanate reacts with a diol to form a urethane linkage. There are a variety of isocyanates to choose from including both aromatic and aliphatic structures. The two most common isocyanates are TDI (toluene diisocyanate or methylbenzene diisocyanate) and MDI (methylene diphenyl diisocyanate or diphenylmethane diisocyanate). The chemical structures of these two chemicals are shown in the figures below.
The many polyols that can be used are broadly divided into ones that are hydroxyl-terminated polyethers or hydroxyl terminated polyesters. The molecular architecture of these polyol chains have a significant impact on the polyurethanes final properties. The number of reactive end groups per molecule and the molecular weight and flexibility of the chain backbone control the degree of cross linking that occurs.

Various additives are also usually required for the formation of certain polyurethane products. Many of these classes of additives are similar to those used in synthetic rubber formulations. Quite often optimizing the right amounts of these additives is key to create a
polyurethane product with desirable properties. Inevitably, compromise is usually necessary between certain final properties and thus a polymer engineer must be able to find the optimum point. The table below summarizes general classes of additives used during the production of polyurethanes in industry.

Table 1 Additives used in the production of polyurethanes (CIEC Promoting Science, 2013)

<table>
<thead>
<tr>
<th>Additives</th>
<th>Reasons for use</th>
</tr>
</thead>
<tbody>
<tr>
<td>catalysts</td>
<td>to speed up the reaction between polyl and polyisocyanate</td>
</tr>
<tr>
<td>cross-linking and chain-extending agents</td>
<td>to modify the structure of the polyurethane molecules and to provide mechanical reinforcement to improve physical properties (for example, adding a polyisocyanate or polyl with more functional groups)</td>
</tr>
<tr>
<td>blowing agents surfactants</td>
<td>to create polyurethane as a foam</td>
</tr>
<tr>
<td></td>
<td>to control the bubble formation during the reaction and, hence, the cell structure of the foam</td>
</tr>
<tr>
<td>pigments</td>
<td>to create coloured polyurethanes for identification and aesthetic reasons</td>
</tr>
<tr>
<td>fillers</td>
<td>to improve properties such as stiffness and to reduce overall costs</td>
</tr>
<tr>
<td>flame retardants</td>
<td>to reduce flammability of the end product</td>
</tr>
<tr>
<td>smoke suppressants</td>
<td>to reduce the rate at which smoke is generated if the polyurethane is burnt</td>
</tr>
<tr>
<td>plasticisers</td>
<td>to reduce the hardness of the product</td>
</tr>
</tbody>
</table>

**Stoichiometric Equations**

Stoichiometry is the quantitative chemical relationship among the components of a chemical reaction. For polyurethanes it is necessary to calculate the ratio between the isocyanate component and the polyl component. In this section, the basic definitions and equations used for polyurethane calculations are presented.
The functionality of a molecule refers to the number of reactive sites that molecule has with reference to the specific urethane reaction. For polyols, an average functionality is used and the equation is shown below.

\[
Average \ Functionality = \frac{\text{total moles } OH}{\text{total moles polyol}}
\]

The hydroxyl number, or the OH number, describes the hydroxyl content of a polyol. It is calculated as:

\[
OH \ number = \frac{56.1 \times 1000}{\text{Equivalent Weight}}
\]

Note that the manufacturer of the polyol provides the OH number for each lot. They arrive at the OH number via a wet analytical method.

Quite often in formulations, multiple polyols are blended together. The resulting mixture’s OH number is calculated as a weighted average.

\[
OH_{\text{mixture}} = OH \ Number_A \times (\text{Wt. } \% \ \text{Polyol } A) + OH \ Number_B \times (\text{Wt. } \% \ \text{Polyol } B) + OH \ Number_C \times (\text{Wt. } \% \ \text{Polyol } C) ...
\]

The equivalent weight is defined as the weight of a compound per reactive site.

\[
\text{Equivalent Weight} = \frac{\text{Molecular Weight}}{\text{Functionality}}
\]

In urethane calculations the ratio of the equivalent amount of isocyanate used to the theoretical amount necessary for a complete reaction is termed the isocyanate index.
Isocyanate Index = \( \frac{\text{Actual Amount of Iso}}{\text{Theoretical Amount of Iso}} \times 100 \)

To calculate the isocyanate parts required you must first calculate the equivalent iso:

\[
\text{Equivalent Isocyanate} = \frac{(\text{Equivalent Polyol}) \times (\text{Isocyanate Index})}{100}
\]

Then you can calculate the required parts of isocyanate:

\[
\text{Parts Isocyanate} = (\text{Equivalent Isocyanate}) \times (\text{Isocyanate Equivalent Wt.})
\]

As with any stoichiometric relationship the final formulation ratio can be defined and scaled linearly for any batch size preparation.
METHODOLOGY

Electrospinner

In this work a customized electrospinning setup is used similar to the schematic below.

Figure 9 Rotating Drum Electrospinning Setup (CSIR-NPL, n.d.)

The equipment used for this setup is as follows:

- Syringe pump
- Syringe needles
  - Various gauges ranging from #18 to #22
- Silicone tube
- Syringe-needle-tube connectors
- 50kV DC Voltage Supply
- Rotating Drum Collector
  - Power supply for the motor of rotating drum
- Aluminum foil (wrap around the rotating drum, Aluminum is the substrate)
- Adjustable stand to rest the collector on
- Needle stand
- Ventilation hood

The images below show the actual electrospinner used for all experiments.
All solutions were prepared in the lab from raw materials. The basic ingredients of the solution included solvents and adhesive polymers. Many solvents were experimented with for each adhesive polymer. The tables below shows the solvents and classes of polymers experimented with.
Table 2 Solvents used in formulation

<table>
<thead>
<tr>
<th>Solvents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl ethyl ketone</td>
</tr>
<tr>
<td>Dimethylacetamide</td>
</tr>
<tr>
<td>Dimethyl sulfoxide</td>
</tr>
<tr>
<td>Chloroform</td>
</tr>
<tr>
<td>Dimethylformamide</td>
</tr>
<tr>
<td>Tetrahydrofuran</td>
</tr>
<tr>
<td>Formic Acid</td>
</tr>
<tr>
<td>Ethyl Acetate</td>
</tr>
</tbody>
</table>

Table 3 Polymers used in formulation

<table>
<thead>
<tr>
<th>Polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic based PSA</td>
</tr>
<tr>
<td>Silicone based PSA</td>
</tr>
<tr>
<td>2 component polyurethane</td>
</tr>
</tbody>
</table>
The solutions were all prepared based on weight ratios with a precision of 0.01 grams. The polymers were dissolved in the solvents in vials with magnetic stirrers. Sufficient time was given, usually overnight, for the polymer to dissolve and create a homogenous blend. The image below shows some examples of solutions being stirred in vials.
RESULTS

**Formulation and Solution Compatibility**

Many different combinations of solvents and polymers were mixed to evaluate their miscibility and solubility. The tables below show the results of whether the chemicals were compatible or not.

Table 4 Polymer-Solvent Compatibility

<table>
<thead>
<tr>
<th>Adhesive Polymer</th>
<th>Solvent</th>
<th>Soluble?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyacrylate PSA</td>
<td>DMAc</td>
<td>yes</td>
</tr>
<tr>
<td>Polyacrylate PSA</td>
<td>THF</td>
<td>yes</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>DMAc</td>
<td>no</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>Dimethyl sulfoxide</td>
<td>no</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>Chloroform</td>
<td>yes</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>MEK</td>
<td>yes</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>NMP</td>
<td>no</td>
</tr>
<tr>
<td>Silicone PSA</td>
<td>DMF</td>
<td>no</td>
</tr>
</tbody>
</table>

In formulation development, the first step would be to identify which chemicals/solvents are compatible with each polymer system. General theories were used to limit the trial and error process however there are always many exceptions to these rules and hence a guess and check method proves to be the most certain. Whether the polymer system is compatible
or not is easily determined visually. The image below shows the difference between a compatible and incompatible solution.

![Figure 12 Image of compatible (right) vs incompatible (left) solution](image)

In the image above, the solution vial on the left is incompatible while the solution vial on the right is compatible. In the incompatible solution we can visually see the white polymer in a solid state in the solvent. The solvent could not dissociate that polymer and hence a heterogeneous mixture is formed which is not suitable for electrospinning. In the compatible solution, we see visual homogeneity throughout the solution. This implies that the solvent was able to dissociate the polymer and create a homogeneous solution proper for electrospinning. For consistent fiber properties, it is vital that the solution show no separation behavior as well. No separation behavior was observed in the solutions even after 72 hours of sitting still in the vial. It is also important that if additives are added they
be very well mixed into the solution. They must be well dispersed as well as distributed in the solution.

**Adhesive Tapes**

Adhesive tapes were successfully manufactured in the lab after much experimentation and fine tuning of the electrospinning parameters. If the parameters were not within an acceptable range, then we could visually see the flaws and defects on the adhesive tapes. For example, the image below shows the droplet defect.

![Figure 13 Droplet defect on Adhesive Tape](image)

From the image above we can see that many droplets are scattered throughout the aluminum substrate. Analyzing the type of defect can help figure out how to readjust the processing parameters to obtain better results. In the case of droplets, the solution viscosity is most likely too low. There is not enough viscoelasticity in the solution to help maintain a fiber geometry. The surface tension of the liquid dominates and forms spherical droplets which land on the substrate and “splash.”
After fine tuning the parameters, which is quite an iterative process of analyzing defects and readjusting accordingly, successful polymer adhesive fibers were spun onto the substrate. The image below shows an example of electrospinning fibers.

![Electrospun fibers on aluminum substrate](image)

**Figure 14** Electrospun fibers on aluminum substrate

In the image above, the fiber diameters are very large to show the visual effect with ease. The same system can be used to make fibers in the micro and nano scale simply by adjusting the parameters.

Once the ideal parameters are determined, it becomes easy to batch produce adhesive tapes. The tape’s backing material can also be changed to other substrates such as transparent PP film, like the image below.
Since the PP film is not conductive, the collector can be tweaked to achieve better and more uniform results. The substrate can also be a Kevlar woven fabric preform shown below.

These adhesive tapes with different backings can display different final product properties. The flexibility of the backing has a great effect on the adhesion of the tape. If the tape is not flexible enough then the adhesive cannot conform to the micro asperities of the surface. This results in smaller contact area and thus decreased adhesion. If the backing is flexible but at the expense of tensile strength, then that also results in weaker end product adhesion. In this case we observe failure not by adhesion or cohesion of the adhesive material, but rather by the fracture of the backing. Therefore proper backing and substrate selection is critical depending on the end use application.

These adhesive tapes were able to demonstrate low peel and high shear adhesion characteristics. This is vital for reusability. The low peel strength allows easy removal of
the tape without damaging the surface. When loaded in the shear direction the tape can withstand higher forces before adhesive failure.
CONCLUSION

Electrospinning presents a novel and efficient method for producing adhesive nanofibers. The adhesion can come from the surface morphology and the chemical formulation of the adhesive system. The surface morphology in this case is of nanofibers produced from electrospinning and the chemical formulations consist of various blends of pressure sensitive adhesives. We have been able to create a working prototype of a reusable adhesive tape in this work. The reusability stems largely from the low peel strength without sacrificing high shear adhesion strength. The tapes do not readily damage substrates upon removal and leave minimal to no residue on the surface. The adhesive can also be coated on various materials. Here we have coated the adhesive on aluminum, woven Kevlar fabric, and Polypropylene film.

The creation of the formulation for the adhesive is quite an iterative process with lots of educated guessing. When creating a new chemical formulation you must understand the fundamental basics and theories however there are often exceptions to these rules. The same method is used when determining the electrospinning processing parameters. Currently there are no defined equations or theories which tell you for example what voltage to use or what flow rate to use. Experience and knowledge play a vital role.

This work is an excellent starting point to explore the possibilities of electrospinning adhesives. Further work can be done to quantitatively characterize the adhesive tapes. Scientific tests, such as the shaft loaded blister test, can be done to obtain adhesion energy of various samples. This can help in further optimizing the formulation and required fiber properties.
REFERENCES


