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Beyond the fiber: Novel spider silk coatings and adhesives

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I. Introduction

Natural spider silks have long been recognized for their combination of incredible strength and elasticity. Spider silk is more elastic than nylon, tougher than Kevlar, and stronger than steel by weight. Due to an inability to farm spiders, much work has been done to produce spider silks in transgenic hosts for large –scale production. Our work was done using recombinant spider silk proteins produced in transgenic goats and the bacteria *E. coli.*

More recently spider silks have also been recognized for their biocompatibility and lack of immunogenicity. Spider silks' incredible strength and ability to be implanted safely within the body makes them highly desirable for use in industry and the medical field. Recently our team has developed a novel procedure to solvate recombinant spider silks in pure water, allowing them to be used safely in a variety of *in vivo* applications.

Uses for spider silk coatings and adhesives are very broad. The focus of the research described here is to coat medical implants and other medical materials. The application of a spider silk coating to materials such as heart stents, implants, and catheters will drastically increase their biocompatibility, decrease the chance of infection as well as recovery time due to decreased tissue growth in response to the foreign object. Coatings can also be functionalized to release antibiotics, antifungals, and other medications. These coatings have shown promise in adhering to silicone and increasing the hydrophilicity of the naturally hydrophobic silicone surface. As for adhesives they have applications varying from the medical field to the textile industry and their strength rivals that of conventional glues on the market. These adhesives can be applied to wood, plastics, stainless steel, silicone, and many other substrates.

Table 1- Thrombotic Blood Fouling

Substrate	No Coating	Spider Silk	Spider Silk with Heparin
Dry Mass Increase			
Silicone Catheter	479%	153%	15.8%
Polyurethane Catheter	429%	233.8%	3.8%
Stainless Steel	2.5%	1.9%	0.08%

II. Methods

The recombinant spider silk proteins we use are made in either the milk of transgenic goats or produced by transgenic E. coli. After expressing theses proteins, they are purified through a process of filtration and centrifugation. We then lyophilize (freeze-dry) the proteins so they can be stored for long periods of time and easily used.

The proteins are solubilized in double distilled water using a microwave and a sealed vial. The high heat and pressure generated overcome the hydrophobicity of the spider silk protein to force it into solution. Coatings are achieved via an airbrush sprayer and adhesives are achieved by simply applying the solution to substrates and allowing them to dry. Properties of the product can be manipulated by using a combination of different spider silks, different silk protein ratios, varying the thickness of the coating, and with the addition of additives such as ammonium bicarbonate

III. Results

__Table 1__ - Allowing blood to clot in the presence of the catheters, it was found that spider silk coated catheters exhibited ~50% less dry mass increase than the controls, whereas the spider silk catheters functionalized with heparin exhibited ~94% decrease in dry mass. See Figure 1 for thrombotic blood study examples.

__Figure 1__ - **A** (control catheter), **B** (functionalized spider silk catheter), and **C** (stainless steel and polyurethane catheters) illustrate the drastic difference in clotting and fouling adherence between controls, spider silk coatings, and functionalized spider silk coatings. A SEM micrograph of a coated polyurethane catheter is shown in **D**. In **E** silicone catheters are coated with spider silk loaded with five different but common antibiotics and demonstrates zones of inhibition against *S. marcescens.* **F** shows silicone wafers coated with spider silk functionalized with an antifungal and inhibition against *C. albicans.*

__Figure 2__ - Spider silk adhesives rival or outperform many adhesives commonly used.

Figure 1 – Coated and Functionalized Materials

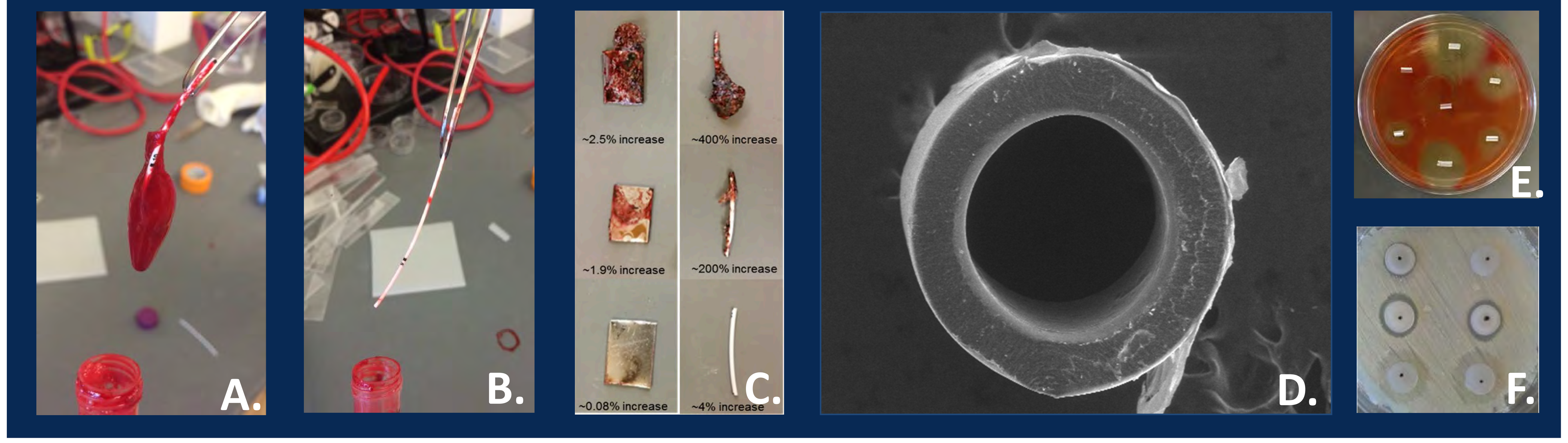
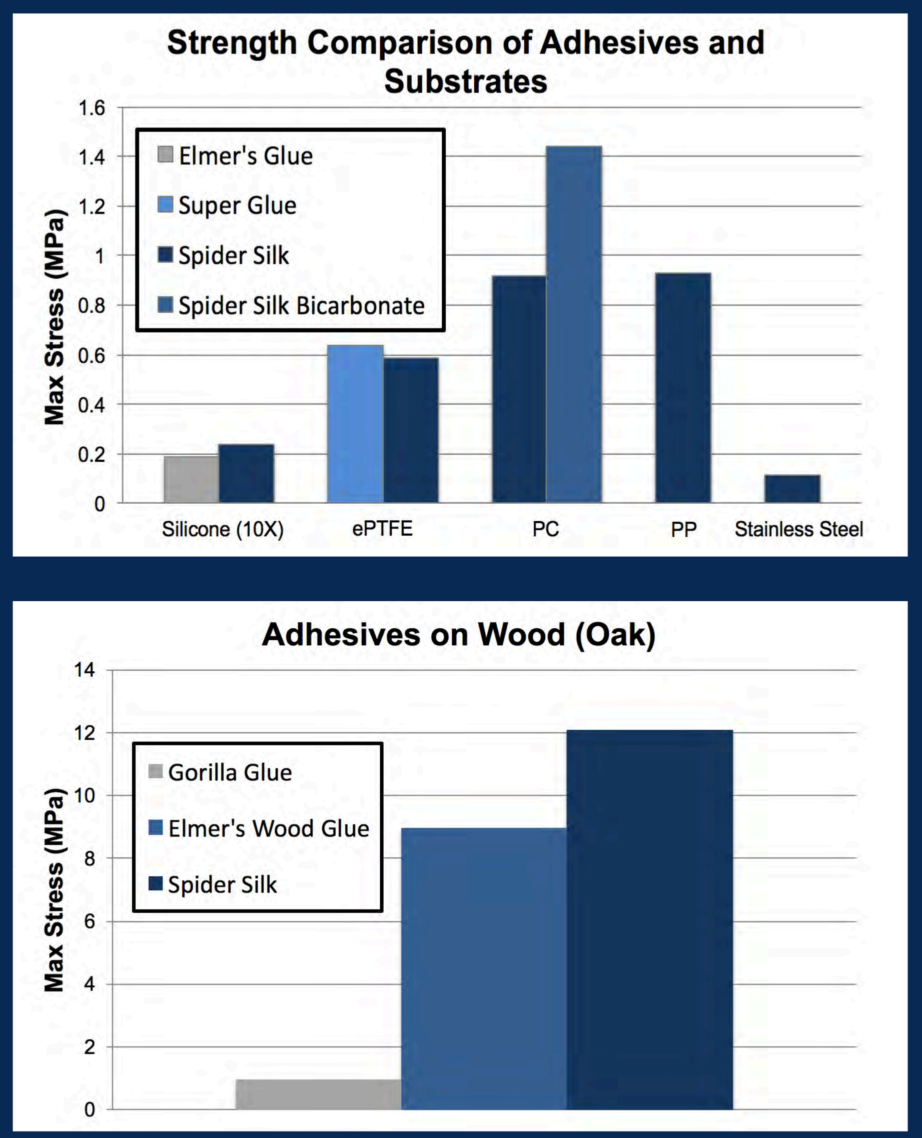


Figure 2 – Adhesives



IV. Conclusions

Adhesives

Water-based spider-silk adhesives are environmentally friendly and perform as well or better than some standard adhesives on the market. These adhesives can be applied to a wide range of substrates, even hydrophobic plastics. Mechanical properties of adhesives can be augmented by combining them with a base-layer coating and various additives.

Coatings

Spider silk coatings can be functionalized to release a variety of different drugs to combat infections and biofilms. The aqueous solvation method allows for easy and cost-effective production of spider silk coatings. These coatings are elastic enough to stay intact on flexible substrates like catheters. Coatings and adhesives can adhere to a variety of surfaces including hydrophobic surfaces like silicone and other plastics.

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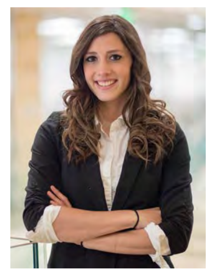

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