# MATERIALS SCIENCE & ENGINEERING

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UCONN
SCHOOL OF ENGINEERING

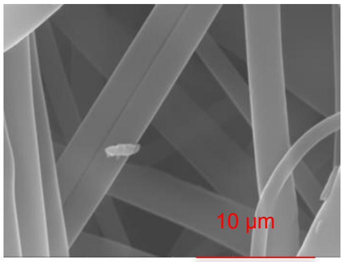
# Team 1: Accelerated Separator Aging Test

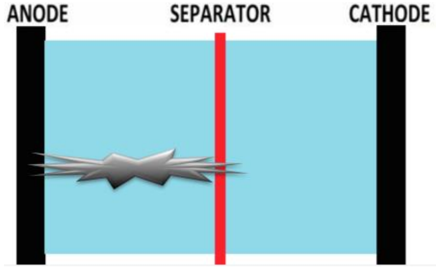
Thomas Bissell and Matthew Dombrowski

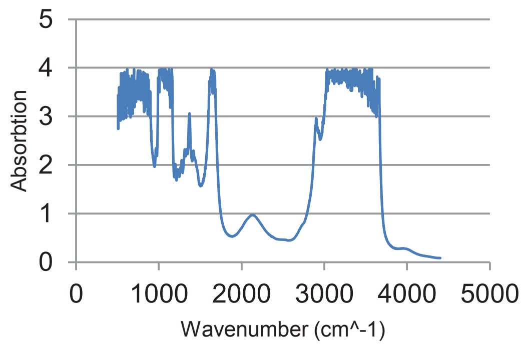
*Sponsored by: BST Systems*
*Sponsor Advisor: Dr. Bryan Hirschorn*

BST Systems produces silver-zinc batteries for specialized applications such as underwater submersibles and space exploration, including the Mars Pathfinder Program. Compared to lithium-ion batteries, silver-zinc batteries have a higher power density and are utilized where battery weight, volume, and safety are primary concerns. However, increasing constraints on performance, longevity, reliability, and operating conditions lead to battery failure often due to internal short circuits. Most commonly these stem from metallic dendrite growth that plates onto the anode and pierces the polymer separator which lies between the anode and cathode. Therefore, improving the separator material to resist dendrite penetration can extend battery life. Four candidate replacement materials were provided by BST Systems that may provide longer lifetimes for future silver-zinc batteries. This study aims to qualify which of the four candidates best resist the effects of the operating environment in a battery.

The polymer candidates are exposed to a KOH solution with AgO particulates as a simulant of the conditions within a packaged battery. KOH is a strong base, which is corrosive and therefore it is important to take the necessary safety precautions including proper labeling, disposal, and handling. Furthermore, since actual lifetime tests would be time inefficient, the polymers and solution are heated to several hundred degrees Fahrenheit for accelerated aging, effectively simulating battery life in hours instead of months or years. Before, during, and following these tests, multiple materials properties are measured to assess the candidate materials. Tensile strength is compared to previously gathered baseline information to determine how the KOH environment affects mechanical properties. Fourier Transform InfraRed (FTIR) analysis identifies any changes in the chemical composition due to KOH attack. Density measurements reveal swelling and uptake. Optical and electron microscopy resolve changes in microstructure. In this manner, recommendations can be made for targeted future scaleup testing by BST Systems and ultimately improved battery performance, reliability, and lifetime.



# Team 2: Hydroxyapatite Coatings on Titanium Alloys

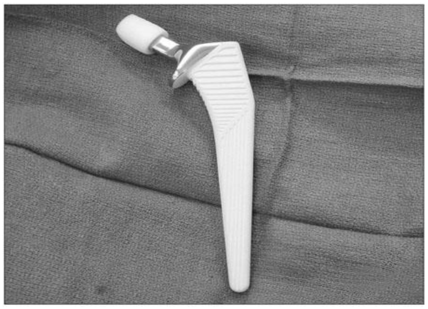
*Sponsored by: Institute of Materials Science/Professor Mei Wei*
*Sponsor Advisor: Changmin Hu*

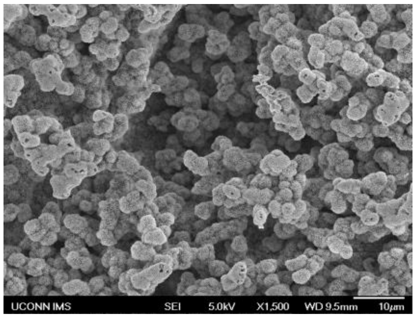
*Jorge Paz Soldan Palma*

IMS INSTITUTE OF MATERIALS SCIENCE

Currently it has been estimated that 250,000 people in the United States have had hip replacement surgery in their lifetime. Not only that but it has been estimated that if this trend continues, by the year 2030 there will be a 180% increase of people undergoing this surgical procedure. This is quite problematic because it has also been noted that the number of physicians who can perform these surgeries has been steadily decreasing in the past decade. It is because of this increasing demand that a need for longer lasting and more efficient prosthetics is needed. Studies throughout the years have stated that the reason for failure of these prosthetics over the years is due to its lack of biocompatibility. Meaning that there is no interaction and fusion of the prosthetic and the bone, which eventually leads to aseptic loosening and ultimately failure. One route that has been taken in accomplishing that goal is by coating a titanium alloy prosthetic with hydroxyapatite, the mineral found in human bones. It is through this method that one hopes are bone ingrowth within the coating. This will provide mechanical stability for the prosthetic implant and a longer duration. The goal of this study is to study the biomimetic coating method for this purpose, study the effects that pH, temperature, surface treatments and drying methods have on the coating's integrity and develop a mechanical test to quantitatively measure the adhesive strength between the coating and the substrate.

The experimental approach involved the biomimetic coating approach, which is the concept of mimicking the body's method of producing hydroxyapatite. This is done by first surface treating Ti6Al4V cylindrical substrates by sandblasting and acid treating. Afterwards a simulated body fluid (SBF) solution, which contains the principal ions needed to produce the coating, is produced. This solution's pH is afterwards fixed and the substrates are then immersed in it. Afterwards the solution is kept for a whole day at 37°C and afterwards dried cautiously. Once this process is complete one can use the many different characterization techniques such as electron microscopy, X- Ray Diffraction or Fourier Transform Infrared Spectroscopy to study the coat and qualitatively determine its adhesive bond strength and structural integrity. It is the goal of this research group to develop a mechanical test that will accurately reveal the coating's true adhesive bonding strength.





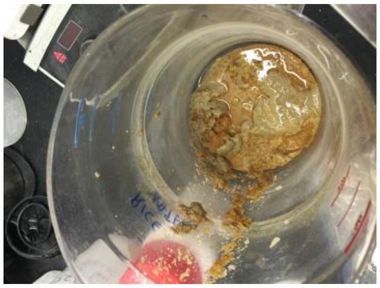

# Team 3: Manufacture of Carbonized Cellulose Fiber Based Filter

*Sponsored by: KX Technologies, LLC*
*Sponsor Advisor: Mr. Bruce Taylor*

*Matthew Lynch (left) and Kevin Linehan (right)*

KX Technologies is making the world a better place through innovation in the water industry. Consumption of pollutants in water is a hazard that many people in advanced societies do not even consider because of the regularity effective filtration. KX Technologies is a leader in water filtration research and development. This development of a large line of product offerings aids the well-being of the humans globally. These filters are typically either carbon block or carbon paper based filters employing the use of activated carbon fibers. To produce an activated carbon fiber, the source material is fibrillated and carbonized. Such a fiber will extract micro and macro pollutants from water. At the simplest level cellulose is a polysaccharide composed of gluten monomer chains. It is a main component in plant cells and is completely insoluble. Fibrillation of cellulose samples will result in fibers that have an extremely high aspect ratio. The ability to maintain a high aspect ratio upon fibrillation is a pivotal variable when it comes to deciding what specific cellulosic fiber source to use. From there the fibrillated fibers are carbonized. This process allows for most of the non-carbon components of the fibers to be burned off. This causes the samples to create new carbon-to-carbon bonds, which in turn causes the formation of carbon plates that will stack on one another to give an extremely high specific surface area per unit volume. This gives water running along the fibers far more material to extract any pollutants that may be present. The fibers are then 'activated' by addition of a combustible compound into the carbonization mechanism. This creates both micro and macro pores that are the part of the fiber are the basis of the mechanisms behind pollutant removal.

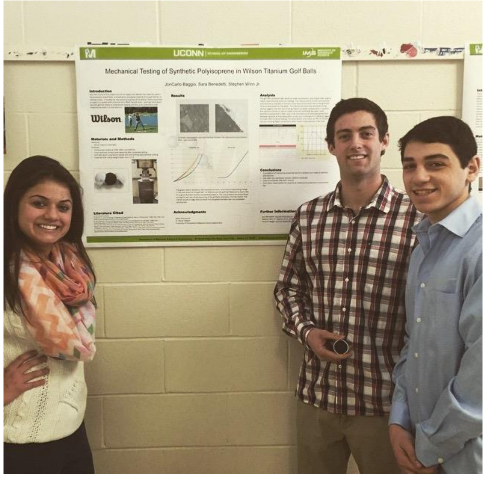
The scope of this project is to examine potential biomass substitutes for filter production that will be more economically viable. Through extensive literature search the materials selected for testing were cotton, coir, hemp, and rice husks. These different cellulosic fibers were processed through fibrillation, carbonization, and activation. Samples were then subjected to testing and characterization. Surface morphology was monitored at the raw, fibrillated, and carbonized steps using visual light microscopy, scanning electron microscopy, and transmission electron microscopy. Raman spectroscopy was used to monitor chemical composition. The filter specific surface area was tested with a BET test. The project benchmark is a chloroform absorption test to test the source material as a viable filter.



# Team #4: Materials Selection and Fire Scenario Model for Improved Full-Scale Fire Safety

*Sponsored by: Marmon Innovation and Technology*
*Sponsor Advisor: Dan Masakowski*

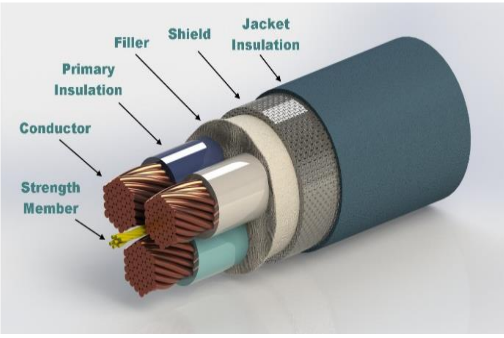
MARMON
Marmon Engineered Wire & Cable LLC
A Berkshire Hathaway Company

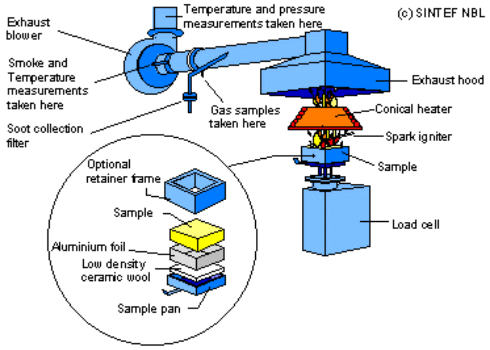


*Sara Benedetti, Stephen Winn Jr., JonCarlo Baggio*

In locations with high concentrations of people, there exists a need to maximize exit time in the event of an emergency. Marmon Innovation and Technology Group produces cables used in transportation infrastructure, and is working to gather and analyze data about how their cables perform in fire scenarios. The cables are constructed with an inner metal conductor and an outer insulation, which Marmon provided 3 different types for evaluation. Two are halogenated cables, a full thickness and a half thickness wall, made of Polyvinylidene Fluoride (PVDF), a cross-linked fluoropolymer that has high corrosion resistance, but can emit carcinogenic gases. The third is a non-halogenated cable, made of cross-linked polyolefin, which is an extrinsically flame retardant polymer. The three cables will be tested in a cone calorimeter at three different heat fluxes: 25 kW/m$^2$, 50 kW/m$^2$, and 75 kW/m$^2$. The cone calorimeter was developed at NIST and provides benchmark data on the burn performance, ignition time, and smoke density of the materials tested. The major tasks of this project are to design a method for interpreting and analyzing the data generated by the cone calorimeter and to present this data in a way that is informative to both Marmon and the fire engineering community.

The results will be used to determine the trade-offs between cable materials, thickness, and burn performance characteristics of the cables. The desired cable will take the longest time to ignite, and once it has caught fire, emit the least amount of smoke with the lowest heat release rate and peak heat release. These parameters will be used to establish an index for burn performance which can be used to rank differing cable materials and geometries. This index may be useful as an input to fire models, which can be used to predict conditions for increasing the egress time in fire emergencies.




# Team 5: Alternative Non-Metallic Materials for Transfer Pump End Cap

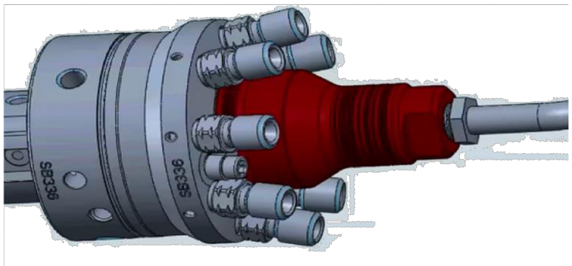
*Sponsored by: Stanadyne LLC*
*Sponsor Advisor: Keith Simpson*


*Kathleen Coleman (left), Victoria Radovic (middle), Zachary Quinn (right).*

Stanadyne
Fueling Innovation

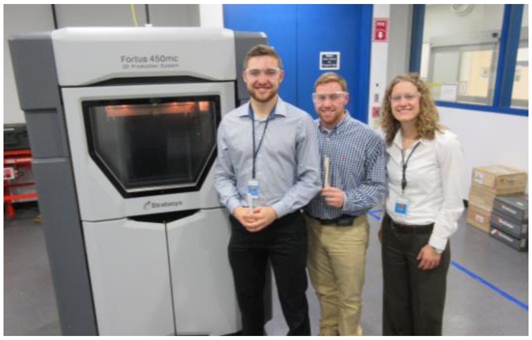
**Project Description**
The transfer pump end cap is an important component in Stanadyne's model DB diesel fuel pumps, used in heavy equipment and trucks. The end cap holds the transfer pump components to the fuel pump head and contains the fuel inlet port. It is currently machined from 1018 bar stock steel and carbonitrided. The part's thin walls and low tolerance internal and external threads leads to difficult machining and potential distortion during heat treatment, resulting in defective parts. As a result, Stanadyne sought to replace the material for the end cap. The project goal was to identify and propose non-metallic materials that are compatible with the diesel environment, meet the structural needs, and are economically feasible. Prototypes were fabricated and tested by Stanadyne for their functionality and long term durability.

Through extensive research, it was determined that a polymer would be the best option to replace the metallic end cap. PEEK, PAI, FEP, and PTFE were deemed the four best polymeric options due to their mechanical properties, working temperature ranges, chemical compatibility, and cost to manufacture. Several tests were then carried out including fluid immersion, tensile testing, and toughness testing. An immersion test was performed on these materials to find the rate of absorption and property changes after being soaked in water, kerosene, and a mixture of fuels at elevated temperatures. Samples of each material were cut into 1" diameter disks and placed in separate glass jars filled with each testing fluid. The jars were then put in a furnace at 100-120˚C and the samples' mass and volume were collected every 12 hours until steady state was reached. Tensile and toughness tests were performed before and after immersion testing to study how soaking the materials changed their mechanical properties. The top two performing materials were officially proposed to Stanadyne for them to begin prototyping.




# Team #6: Design of Coating for Fused Deposition Modeling Material

*Sponsored by: UTC Aerospace Systems*
*Sponsor Advisor: Colette Fennessy*



*(From left to right) John Scovill, Jake Lampron, Colette Fennessy*

UTC Aerospace Systems

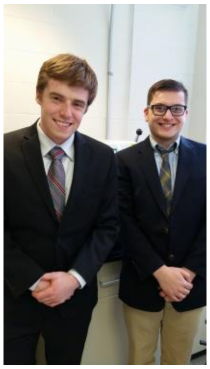
UTC Aerospace Systems provides heat exchanger assemblies to air framers. The Lower Recirculating Heat Exchanger is installed in the Liquid Cooling System (LCS) and is used to cool recirculated air from the airplane cabin and provide cooling to the Pack Control Unit (PCU). Part of the component design includes plastic mock inlet and outlet ducts being fabricated through fused deposition modeling (FDM), an additive manufacturing process. The mock-ups will be used for rig testing before implementing final, expensive metallic materials.

This project aims to design a plastic mock-up air duct that can withstand the environmental conditions of the LCS. One of the biggest issues with FDM and additive manufacturing in general is the porosity caused by the layer by layer fabrication process. The porosity leaves FDM parts susceptible to liquid and/or gaseous environments, like the LCS, where the fluids will permeate the parts. While additive manufacturing is advantageous in terms of schedule and cost, the mock-ups are not useful unless they can be tested without permeation. To prevent permeation, this project will design a coating to be applied to the FDM parts that will make the additive manufacturing process feasible for fabricating air ducts

Success of this project will be based on preventing permeation of fluids into additively fabricated plastic parts. To accomplish this, multiple FDM materials and coatings were investigated. Three materials produced by Stratasys; ASA, Ultem 9085, and Nylon 12, were coated with three coatings; an epoxy (BJB-TC-1614), a polyurethane (ANAC 58 Series), and an adhesive (Loctite RTV Silicone). The merits of each coating-material combination was quantified by two main metrics, the adhesion between the coating and substrate, and the amount of permeation allowed into the part. Adhesion testing was accomplished using a cross-hatch tape test to observe the bond strength of each test piece. The permeability was tested by submerging the parts in fluids from the LCS environment (60/40% mixture of propylene glycol and water) for varying exposure times and recording the change in mass due to permeation. Mechanical testing was then used as a supplementary metric to quantify the structural integrity of each test combination. Tensile and hardness tests were carried out to accomplish this as well as provide a characterization standard for future research conducted by UTC Aerospace Systems on FDM materials and practices.

# Team 7: Substantiation of the Static Mechanical Properties for Cold-Worked Aluminum

*Sponsored by: UTC Aerospace Systems*
*Sponsor Advisor: Stephen Pasakarnis*

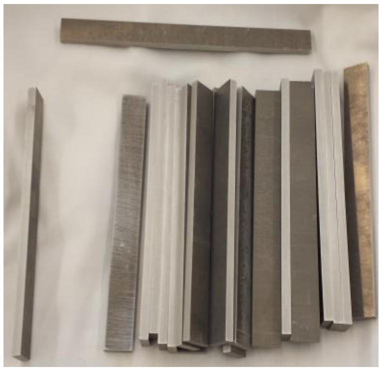


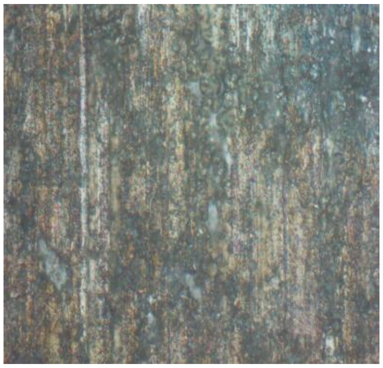
*Shown: William Masinda, Dale Gouveia*

UTC Aerospace Systems
Where ingenuity takes off

Aluminum is preferred for Air Management Systems components due to their favorable strength to weight ratio and affordability. Aluminum heat treatments are characterized in a series of abbreviations posted after the aluminum series number. As the set system of abbreviations for temper designations follow, -O is a full soft or annealed sample, -T stands for heat treated to produce stable tempers. The objective of this project is to investigate the varying levels of plastic strain imparted prior to heat treatment on the mechanical properties of –T62 aluminum. It's crucial to know how the microstructure changes throughout the process of plastic deformation before heat treatment as during the heat treatment process precipitates will develop and try to alleviate the stress developed through pre-straining. This will be compared to known values of, UTS (42ksi) and for yield strength (36ksi) for 6061-T6 plate (thickness .4in.). Strain levels in excess of 15% will be of particular interest as they have not been tested previously. The general thought is that if the materials can be strained above 15% that other methods and parts can be produced using this form of cold working. If the material is a success at strains above 15% it companies can save money and time producing air management system products. We will be testing 24 samples, with 3 samples each corresponding to a specific pre-strain (0%, 5%, 10%, 15%, 20%, 22%, and 24%). Microstructure of each pre-strain before and after heat treatment will be examined.

Changes in the mechanical properties of the Aluminum are measured through tensile tests for each pre-strain percentage. Samples are pulled to failure, and the corresponding ultimate tensile strength, yield strength, and maximum elongation was found for each pre-strain based on corresponding stress-strain curves. Scanning Election Microscopy and Visual Light Microscopy were employed to see changes in microstructure based on the pre-strain percentage before and after heat treatment. The aging process of for –T62 Aluminum involves the formation of β $Mg_2Si$ phases that strengthen the Aluminum. Imaging is important in visualizing differences in the precipitation of phases amongst the different pre-strains. Being able to confirm little to no reduction in mechanical properties of 6061-T62 Aluminum based on testing results and imaging would be largely valuable for improving efficiency at UTC Aerospace Systems.



# Team 8: Testing & Verification of Machine Learning Aluminum Force Fields

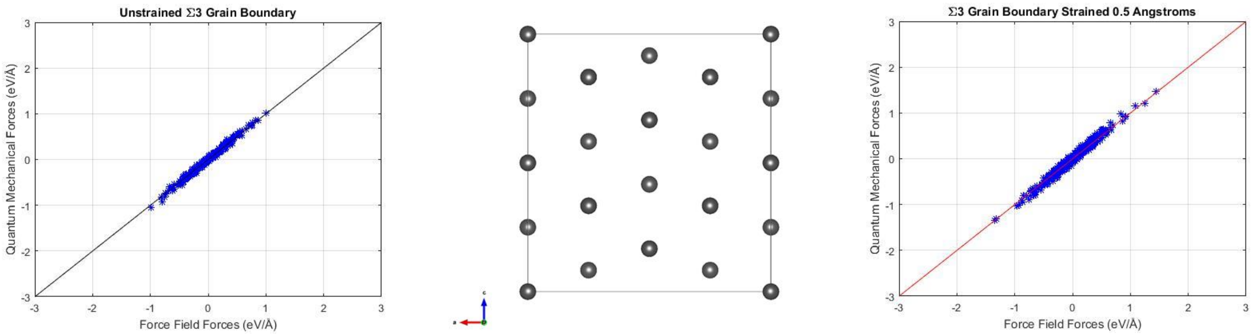
*Sponsored by: Pratt & Whitney*
*Sponsor advisor: Dr. Amra Peles (UTRC)*

*Aliya Carter (left), Kevin Co (right)*

Pratt & Whitney
A United Technologies Company

Computational materials sciences are quickly gaining traction in industrial applications in order to explore volatile and obscure process as well as to guide experimentation, avoiding blind, trial and error approaches. Unfortunately, limitations to computational resources prevents the large scale, high accuracy calculations needed to truly revolutionize the industry. In an effort to unite highly accurate density functional theory calculations to much larger scale (but less accurate) molecular dynamics calculations, a data driven scheme to predict interatomic force fields using a training data set of density functional theory calculations has been developed. The method allows for molecular dynamics calculations to be done with the accuracy of density functional theory by generating an interatomic force field using a statistical model trained on density functional theory data. As with any statistical model, the force field is not accurate for any situation sufficiently outside of the dataset and no testing has been done to explore the domain as of yet.

The objective of this work is to stress test the “machine-learning” force field by using it to run molecular dynamics calculations for a range of atomic environments. This data is then checked with density functional theory calculations in order to improve the data set of the statistical model. The experimental procedure for testing the machine learning generated force field is broken down into structure selection and generation, molecular dynamics using the generated force field, first-principles (DFT) molecular dynamics and comparison/recommendation. To evaluate the success of the force field, the magnitude of the force on each atom as predicted by the force field and first-principles is calculated. These values are plotted against themselves in a parity plot for qualitative assessment. If a low correlation between the two methods is seen, the structure is placed directly into the training data for the force field. Atomic environments tested include a sigma-3 grain boundary in equilibrium and strained 0.1, 0.3 and 0.5 Angstroms. The comparisons for the grain boundary configurations proved accurate, serving as validation for the machine learning force field. Testing of bulk systems in uni-axial and bi-axial tension and compression along with vacancy clustering are currently in progress. All configurations are defined for an FCC Aluminum crystal structure.



# Team 9: Hexavalent Chromium Chromate Replacement Product Performance Verification

*Sponsored by: General Electric – Industrial Solutions*
*Sponsor Advisors: Peter Greenwood, PE and Leonardo Mascarenhas*
*Faculty Advisors: Pu-Xian Gao, Ph.D. (MSE) and Zbigniew Bzymek, Ph.D. (ME)*

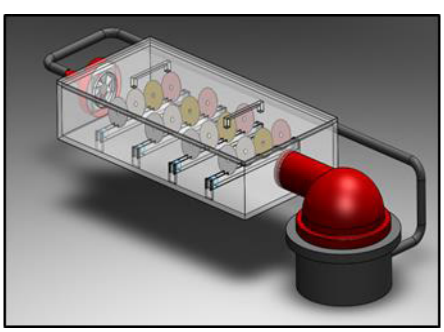
*From Left to Right: Alex Choi (ME), Eric DeLea (MSE), Geri Gonxhe (ME), Tyler Luneski (ME), and Vincent Ybanez (MSE)*

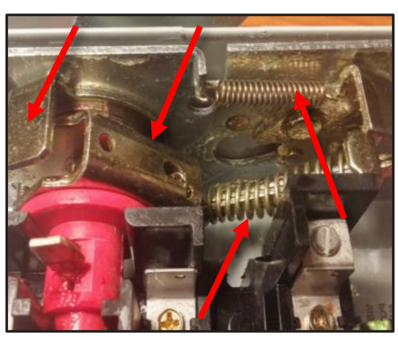
GE
Industrial Solutions

General Electric - Industrial Solutions (GE) is a company that provides a wide variety of products and services in the electrical distribution business. GE has tasked us with identifying a suitable replacement for Hexavalent Chromium Chromate passivation. This material is plated on many components in GE electrical equipment due to its corrosion resistance. However, due to changing regulations and the health risks of HCC, the sponsor has determined that it is necessary to remove the plating from production by 2019.

In order to determine the viability of potential substitute materials, the team of Material Science & Engineering (MSE), and Mechanical Engineering (ME) students produced custom testing rigs to evaluate material wear and corrosion performance. The construction of these rigs and the fabrication of the 400+ testing coupons were the primary physical deliverables of this project. The wear rig allowed the team to determine mechanical performance on the basis of mass loss. In the evaluation of mechanical performance, the coated test coupons were revolved on a testing plate while a flat, coated column contacted the surface to wear the plating. After a certain number of cycles, the coupons were subjected to environmental testing. The corrosion rig was designed to provide aggressive corrosion on the worn coupons, and was modeled after the industry standard salt fog test. The worn test coupons were immersed in a humid salt fog test chamber and held at temperature until corrosion started. A series of calibration checks were completed to evaluate the UConn test severity to ASTM standard testing.

The team examined three different plating materials (JS 600, trivalent chromate, and zinc phosphate) and compared their performance to that of the original HCC plating. Optical microscopy, scanning electron microscopy, profilometry, and surface metrology techniques were employed to determine which plating was likely to meet the consumer standards necessary for replacement. The large set of data on volume loss, mass loss, and surface degradation provided good metrics for the evaluation of material suitability. These tests were done before and after the corrosion process. The resulting comparative analyses drove the final recommendation of the best candidate material for the sponsor on the basis of mechanical and environmental performance.





# Team 10: Porosity comparison of the X-ray $\mu$CT to that of Archimedian freezing

*Sponsored by: Pratt & Whitney*
*Sponsor Advisor: Dr. Shayan Ahmadian*

*Students: James Fitzgerald, Dariel Sanchez*

X-Ray micro-CT machine is capable of performing high cost resolutions scans on various specimens allowing one to give an in-depth study of the scanned specimen. However, there exist multiple challenges with the X-Ray micro-CT machine such that an alternative analysis technique is sought after. The common challenges of utilizing the X-Ray microCT are the fact that it involves a high amount of time, cost, and that there are limitations on sample size and the corresponding scan resolution. The goal of this project is to compare micro-CT analysis to Archimedean method for measuring porosity of a sample which contains both "open" and "closed" pores. To ensure liquid penetrates into the "open" pores of the specimen and that "open" and "closed" pores are distinguished, a modified Archimedean method, "Archimedean Freeze", is pursued with a Potassium Iodide+ Iodide Solution instead of water. Once the Potassium Iodide+Iodide solution infiltrate the pores, it will stain the specimen, leaving a trace behind in the open pores of the specimen. This trace left behind can be detected through the X-Ray micro-CT, where observations can be made in regards to the viability of the "Archimedean Freeze" method by measuring and distinguishing between "open" and "closed" pores. This method can help assess whether the difference in porosity measured by the Archimedean method as compared to micro-CT is due to the closed pores not being infiltrated. If the "Archimedean Freeze" method proves to be successful, one would be able to test for porosity on a multitude of specimens at significantly low costs and lower lead time.


*Figure: Photo of micro-tomography analysis instrument.*

# Team 11: Quantum Mechanical pKa Predictions of Drug-like Molecules

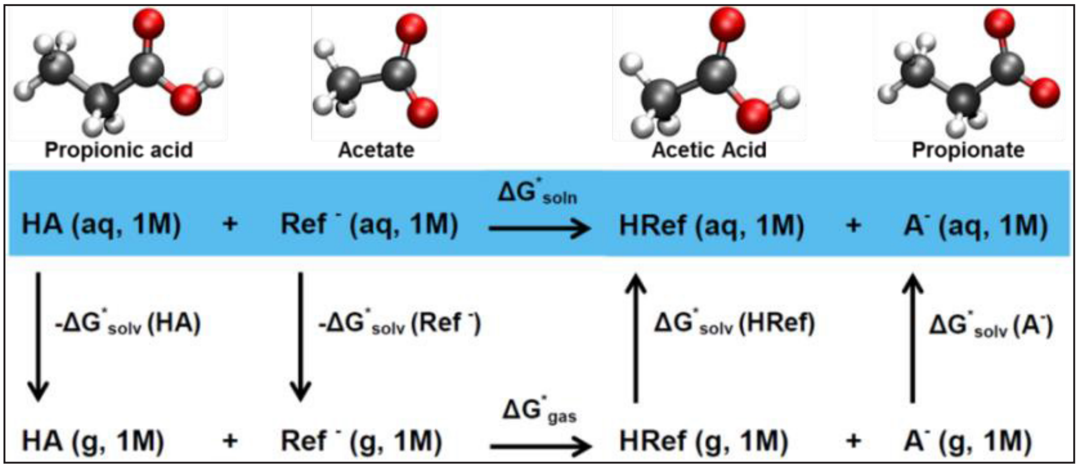
*Sponsored by: Pfizer Inc.*
*Sponsor Advisor: Geoffrey Wood*

*Rebecca Stern, Senior Undergraduate, Materials Science and Engineering, University of Connecticut*

One of Pfizer Inc.'s goals is to improve their ability to predict molecular and solid state properties in order to aid drug design and delivery. A molecule's degree of dissociation in solution is a vital characteristic that determines a number of key properties such as, formulation, stability, bioavailability, absorption, and salt formation. The pKa defines a molecule's extent of ionization in solution and in the pre-formulation stage the pKa value assists in deciding which salts are viable targets for drug design. Empirical methods for pKa determination are fast but potentially produce large errors. In these situations *ab initio* quantum mechanical investigations may present a more accurate alternative for pKa determination for drug-like molecules because these calculations do not depend on training sets or experimental information. Although using quantum mechanical computations to predict the pKa value leads to marginal increases in the cost of research, it is advantageous to use when faster and less accurate approaches produce inconsistent pKa results or crucial design decisions are being made and more certainty is needed.

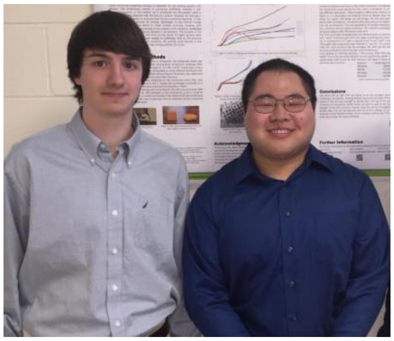
A variety of *ab initio* quantum mechanical calculations and statistical analysis of the obtained results were preformed to establish the accuracy of currently used conventions for pKa predictions in drug-like molecules. An understanding of the advantages and disadvantages of each method was obtained. To conduct this investigation, computational research was done using the Gaussian code. This program was used to predict energetics, structure, and thermodynamic properties of molecules in the gas and solution phases. These energies were then used to calculate the molecule's pKa, which was then compared with the corresponding experimental data.

The thermodynamic cycle shown in the figure below is a strategy that was employed to calculate the pKa value of a molecule of interest (propionic acid in the example). It was concluded that the choice of reference base (Ref- in the figure) plays a critical role for achieving high accuracy. However, further research is being conducted to discover a reliable way of identifying these references.



# Team 12: Additive Manufacturing Processing Design for 17-4PH Stainless Steel

*Sponsored by: Medtronic*
*Sponsor Advisor: Dr. William Powers*

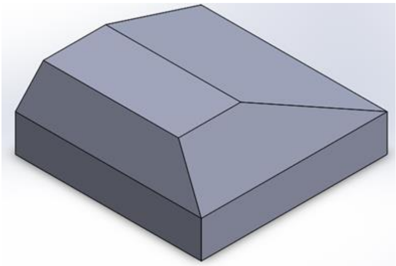


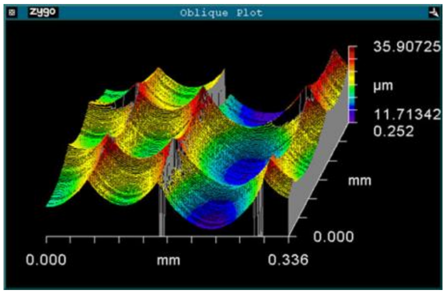
*Design Group: John Corsi (left) and Kevin Yong (right)*

Medtronic is a medical device company whose mission is “to contribute to human welfare by application of biomedical engineering in the research, design, manufacture, and sale of instruments or appliances that alleviate pain, restore health, and extend life.” There has been recent interest in researching the viability of utilizing the additive manufacturing process in the design and creation of various parts for medical instruments. Some biomedical devices require high tolerance parts as well as quality surface finish. The interest in additive manufacturing is the potential to create complex and intricate parts while maintaining minimal surface roughness.

The aim of the design project was to utilize the Direct Metal Laser Sintering Process (DMLS) found in the 3D Systems ProX 300 system using 17-4PH stainless steel to manufacture samples at variable parameters. The samples were generated based on a computer aided design model that focused on the faces of the sample at various angles. The surface roughness of the resulting samples was then analyzed using the aid of a Zygo 3D Optical Scanning Interferometer profilometer. The core objectives were to improve the surface roughness of samples in addition to establishing a qualitative relationship between the laser parameters and the surface roughness parameter.

The variable parameters that were being explored include the laser beam power, laser speed, and beam overlap distance. These 3 factors will have 2 levels which will result in the creation of 8 samples. For consistency, each sample will be duplicated, resulting in 16 samples. One sample will be fabricated with default settings as a control which will result in a total of 17 samples. Because each sample had 6 faces (0°, 10°, 30°, 50°, 70°, 90°) and a total of 17 samples, 102 Zygo measurements were necessary in order to effectively observe the relation between the parameters of the 3D Systems ProX 300 system and the surface roughness parameters of the samples.





# Team 13: Electron Beam Welding of Additive Manufactured 17-4PH Steel

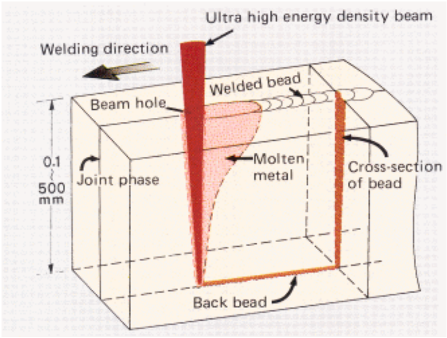
*Sponsored by: PTR-Precision Technologies, Inc.*
*Sponsor Advisor: Dr. Amber Black*


*Nicholas Ninivaggi (L) and Brian Dos Reis (R)*

PTR
PRECISION TECHNOLOGIES, INC.

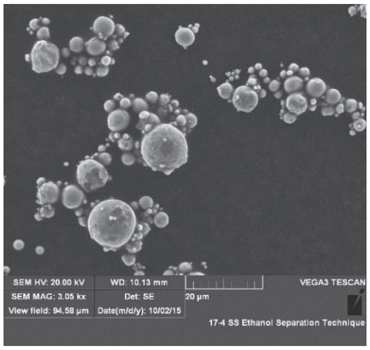
PTR-Precision Technologies, Inc. specializes in electron beam welding and is interested in the performance of additive manufactured stainless steel components when subjected to this joining technique. Determining how electron beam welding affects the strength of the material can identify whether or not additive manufactured parts can be safely welded by PTR for their clients. With additive manufacturing becoming more common in industry, PTR needs to have a certain level of confidence that they can weld these parts, or at least know how to adjust manufacturing or welding parameters to safely do so. By developing guidelines for welding additive manufactured parts, PTR can be assured that they can continue to serve a wide range of customers in a variety of industries.  In order to assure customers that electron beam welding can be used on additive manufactured components, PTR must have data regarding how the strength of additive manufactured parts change when welded. If there is no significant change in the properties of these components, it will be safe for customers to have their parts electron beam welded. If not, PTR can suggest methods for manufacturing so that they can be safely welded. By developing these guidelines, PTR will be able to maintain a diverse customer base including manufacturers who utilize additive manufacturing.

This studied additive manufactured 17-4PH stainless steel powder using selective laser melting; both being common a material and processing technique used in additive manufacturing.   This experiment will determine how much of a variation in strength this material has from traditional wrought 17-4PH steel.  In testing the mechanical properties, both tensile and hardness testing were performed on both fabrication techniques in welded and non-welded conditions.  Microstructural analysis was also done to determine how processing changed mechanical properties.  Finally, the materials were compared in their varying processing states in order to calculate a percentage difference between them and determine whether additive manufactured steel is safe to use in industrial applications when electron beam welded.




*Typical electron beam weld process*

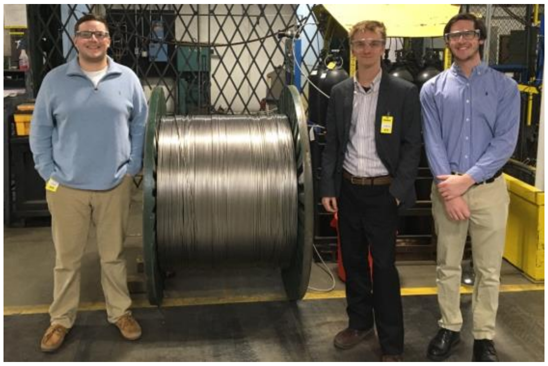
*Electron beam welder at PTR*




*SEM imaging of 17-4PH powder*

# Team 14: Ultra-High Pressure Tube Encapsulated Conductor (TEC) Development

*Sponsored by: RSCC Wire & Cable, LLC*
*Sponsor Advisor: Scott Magner*

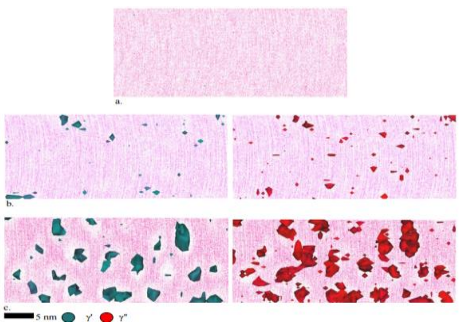


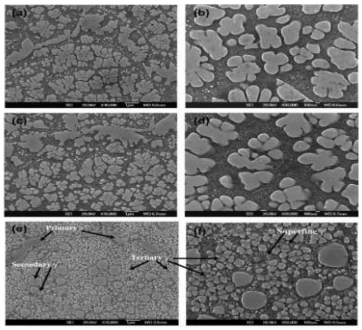
*Team 14 members from left to right: Nate Gamm, Michael Matysek, and Greg Gagne*

RSCC Wire & Cable provides an array of engineered cables to clients in a variety of industries. More specifically, many of their cables function as tube encapsulated conductors (TECs). Tube encapsulated conductors are conducting wires (often copper) surrounded by a polymer shell and bonded to a metallic tube covering. As RSCC is one of few companies that offer such products, high quality must be guaranteed. One industry where their products thrive is in oil and gas production. These products serve as information lines between sensors found in oil wells, and operators found at the surface. Such sensors provide readings like well temperature, pressure, and composition. These sensors are extremely important, as without them companies would be blindly drilling into wells. The demand for these products is large, and as stated before, high quality must be nothing short of guaranteed.

The purpose of this project is to fabricate a stronger cable capable of withstanding extremely high working pressures (30,000psi) with a large working range (yield at 125,000psi at .2% offset). Using Inconel-825 as an alloy, a strengthening mechanism must be chosen so that the product meets the given specifications. The chosen mechanism must be both cost effective and practical in order to keep costs at a minimum.

Conventional materials science gives four general options for strengthening a metal; precipitation hardening, work hardening, solid solution treatment, and grain size reduction. Nickel-based alloys (like Inconel-825) often don't use grain size reduction for strengthening, so this process should be avoided. Additionally, the composition of the material cannot be altered, so solid solution treatment is eliminated. Precipitation hardening is tough for this application, as the alloy must be treated before the welding process. Once welded, the polymer binder cannot withstand typical aging temperatures, so any precipitation hardening would have to occur prior to the rolling and welding of the material on site. RSCC receives this specific alloy in an annealed state, so cold working is the leading candidate for strengthening. By conducting tests on both annealed and cold rolled samples, an ideal rolling technique will be developed for the strengthening of this alloy.





# Team #15: Design of Continuous Annealing Process for Improved Efficiency of Wire Annealing

*Sponsored by: Ulbrich Shaped Wire*

*Sponsor Advisor: Jim Schraml*

*From left to right: Nathan Eichacker, Matthew Lundin, Matthew Mckinney*

We Deliver Precision®

Ulbrich Stainless Steels and Special Metals is a family-owned company headquartered in North Haven, CT which is relied on by the medical, aerospace, automotive, and electronic industries along with many others. Ulbrich is having difficulty cooling wire coming out of their annealing furnace. To make up for this, the wires are being drawn through the furnace at low speeds in order to allow proper cooling at the end of the unit. In order to run the wires through at an acceptable speed, the cooling apparatus must be altered such that the wires can run through quickly but also exit the cooling system at safe handling temperatures. This project was aimed toward an evaluation of the current annealing process for both round and flat wires, some made of stainless steel and others nickel alloys. The focus is to improve the efficiency of the annealing process by altering the cooling apparatus and beneficially adjusting wire speeds. Ideally, proposing a formula for speeds of both round and flat wire will allow effective production and improve ease of furnace operation and adaptability. When implementing this new formula to increase annealing speed, safe handling temperatures when leaving the cooling system are paramount. Maintaining physical and mechanical properties to match customer specifications are other essential constraints.

Mechanical testing was performed on wire samples before and after annealing in order to determine customer specifications for the product. Stress-strain relationships, Rockwell hardness, and grain size were determined for each sample. The parameters for successful annealing were determined as an increase in elasticity and toughness, and a slight increase in grain size. These property changes, brought on by annealing, increase the lifetime and performance of the finished product and must be held by the new annealing process. In order to properly anneal the wire running at a higher speed, the hydrogen unit should be moved closer to the exit in order to allow proper heating over a shorter amount of time. In order to cool the annealed wire using less time, a water spraying system should be implemented in order to allow safe handling without quenching the material into a martensitic state. Testing of the new finished wires is crucial to ensure the results of annealing have not strayed from customer specifications.

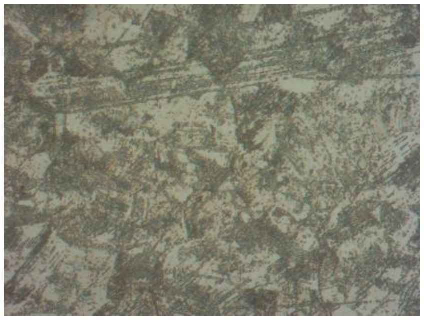


*Figure 1: Micrograph of 305 stainless steel flat wire before entering the annealing furnace*

*Figure 2: Wires of different shapes and compositions entering the annealing furnace*

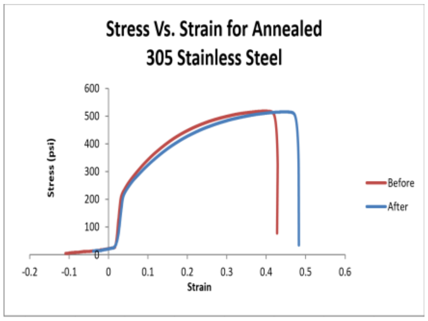
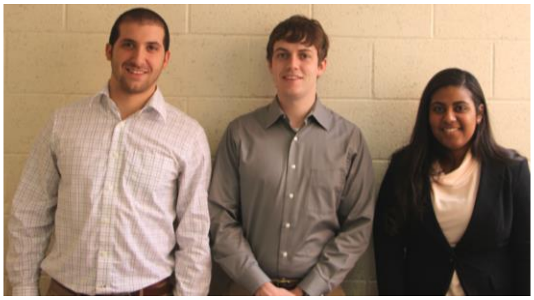



*Figure 3: Tensile testing results showing before and after effects of annealing on 305 stainless steel*

# Team #16: Reliable Repair of Composites using Additive Manufacturing

*Sponsored by: Sikorsky Aircraft Corporation*
*Sponsor Advisor: Tim Fekete*



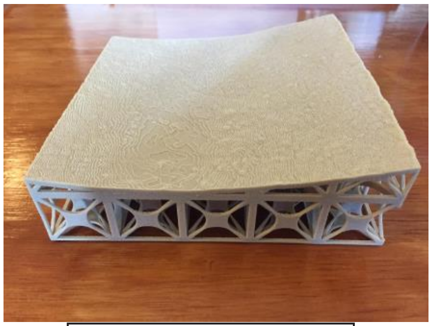
*From left to right: Jeremy Higgins, Michael McGeever, and Amy Hernandez*

Sikorsky

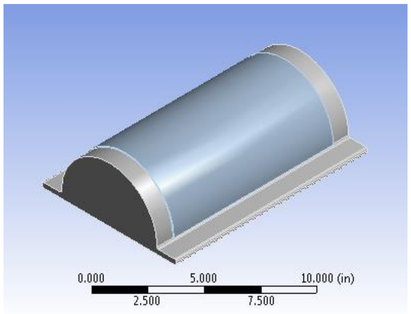
As composite materials begin to replace metals in many structural components in rotorcraft, a reliable and adaptable method must be developed to repair damaged composite parts. Traditional methods typically used for the repair of metal parts such as welding are not viable repair options for composites. Instead, the damaged area will be scanned and translated into a 3D computer model. A customized mold could then be 3D printed which would be used to lay up and cure the composite patch. Then, the cured patch could then be used to repair the damaged composite.

High dimensional fidelity of composite patches is required since they must fit precisely into the damaged area. Thus, the mold must be thermally stable and keep its shape constantly during the patch curing process at an elevated temperature. The glass transition temperature of polymer mold needs to be higher than 350ºF to avoid softening of mold. Also, the thermal expansion coefficient needs to be minimal. Furthermore, since resources will be limited during field repair scenarios, the mold material must be recyclable so that it can be ground up and used to create a new mold. Thus, thermo-plastic would be a good candidate.

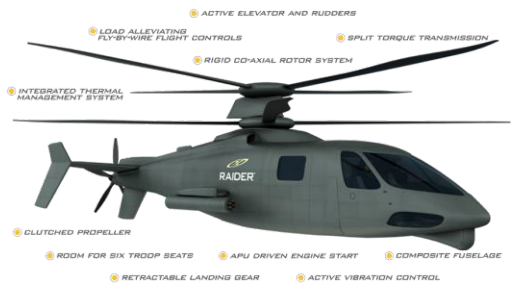
The mold material that was chosen was a polyetherimide based polymer, ULTEM 1010. It was chosen because it meets the requirements listed above. An additively manufactured mold was produced in the shape of a cylinder. This shape was chosen as it has only one direction of curvature and will be easy to visually inspect for dimensional inaccuracies. The composite was laid up using this mold between 6 and 18 layers thick. This was done as this is an industry standard for the composites used in rotorcraft. Residual stresses within the composite patches were analyzed to determine the effectiveness of the 3D printed molds for composite patch production. Visual inspection was also done to study any changes in dimension of the mold itself due to thermal expansion during the curing process as this could affect the dimensions of the final patch.



(1) 3D Printed Mold




(2) CAD model of composite laid up on 3D printed mold




(3) Sikorsky S-97 Raider Helicopter, relies heavily on composite parts