

## Structure and Materials 2

### Cornerstone Electronics Technology and Robotics III

(Notes primarily from “Underwater Robotics – Science Design and Fabrication,” an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
  - Prayer
- **Metals Used for Underwater Vehicles Structures:**
  - Pure metals – a pure metal only consists of a single element.
    - Most pure metals are either too soft, brittle, or chemically reactive for practical use.
    - Creating alloys by combining different ratios of metals modifies the properties of pure (elemental) metals to produce desirable characteristics which the individual elements alone do not possess. Elemental metals such as aluminum, iron, nickel, copper, gold, silver, and titanium are often alloyed before they are sold in order to improve their properties.
  - Alloy – a metal made by combining two or more metallic elements, especially to give greater strength or resistance to corrosion. Brass is an alloy of zinc and copper.
    - Common alloys include steel, stainless steel, brass, and bronze.
  - Advantages:
    - Hard
    - Stiff
    - Wear-resistant
    - Excellent strength-to-weight ratio
    - Can be machined, cut, drilled, bent, welded, and cast
  - Disadvantages:
    - Prone to corrosion – more on corrosion prevention later
  - Structural metals that are used in underwater vehicles:
    - Steel – A commercial alloy of iron which contains an amount of carbon (up to 1.7%) as its essential alloying constituent. Steel is malleable under suitable conditions. It differs from cast iron in that steel is more malleable and has lower carbon content.
      - Although steel is a dense material, it forms vehicles that are lighter due to its high strength-to-weight ratio.
      - The material of choice for large underwater vehicles.
      - Disadvantages:
        - Susceptible to corrosion or rusting; given sufficient time, oxygen, and water, any iron mass will eventually convert entirely to rust and disintegrate.
        - Most steel alloys distort magnetic fields which hinders compass readings.

- Stainless steel – A steel alloy defined by a chromium content of at least 10%. Other elements are sometimes added to augment corrosion resistance.
  - Ideal for underwater applications
  - Type 316 is usually regarded as the standard “marine grade” stainless steel.
  - Used extensively for hydraulic, pneumatic, and electrical fittings and fasteners
  - Disadvantages:
    - Expensive – not cost effective for large underwater vehicle frames
    - More difficult to machine than other steel alloys
    - Susceptible to stress cracking
    - Requires special welding equipment
- Aluminum – A silver-white metallic element. Its properties make it light in weight, ductile, malleable, and resistant to corrosion or tarnishing.
  - Advantages:
    - Corrosion resistance
    - High strength-to-weight ratio
    - Relatively easy to machine
    - Reasonable cost and readily available
  - 6061 and 6063 aluminum alloys are widely used in underwater vehicles.
  - Disadvantages:
    - Corrodes in seawater
- Titanium - A lustrous white metallic element. Titanium is strong, has a low density, and is highly corrosion resistant. Used in alloys formulated for aircraft construction because of its low weight, strength, and high-temperature stability.
  - Advantages:
    - Excellent corrosion resistance in seawater
    - Very high strength-to-weight ratio
    - High resistance to fracture
  - Disadvantages:
    - Much more expensive than steel. For example, a ¼”x 1”x12” piece of titanium from McMaster-Carr presently costs \$36.32 while a piece of 1018 low-carbon steel is \$18.21.
    - Special practices must be followed to machine titanium.
    - Requires special welding techniques
- Brass – A yellowish alloy of copper and zinc. Usually composed of 67% copper and 33% zinc.
  - Advantages:
    - Can be readily machined
    - Corrosion resistant

- Has excellent thermal conductivity, making it a first choice for heat exchangers (radiators).
  - It has been shown that MRSA and Clostridium difficile, which can be spread by touch, will die in a few hours on copper/brass surfaces.
  - Today almost 90% of all brass alloys are recycled.
    - Naval brass is composed of 40% zinc, 59% copper, and 1% tin. It is made for high corrosion resistance in seawater.
- Perform Structures and Materials Lab 3 – Working with Metals
- **Plastics Used for Underwater Vehicles Structures:**
  - Plastic – a substance composed predominantly of a synthetic organic high polymer capable of being cast or molded
  - Advantages:
    - Low cost
    - Readily available
    - Excellent corrosion resistance
    - Ease of machining and fabrication
    - Moderate strength-to-weight ratio
  - Disadvantages:
    - Deteriorates when exposed to sunlight and chlorine as in pools
    - Moderate strength-to-weight ratio
    - Can absorb minute amounts of water
    - The previous characteristics make it less suitable for large and/or deep diving vehicles
  - The majority of small, inexpensive underwater vehicles are made of plastics.
  - For a list of plastic properties comparison, see: [Plastics Materials Selection Guide](http://www.iplasticsupply.com/materials/abs-cycolac-absylux-royalite-sheet-rod/) at <http://www.iplasticsupply.com/materials/abs-cycolac-absylux-royalite-sheet-rod/>
  - For general descriptions for many plastics including some marine plastics, see: <http://www.midlandplastics.com/index.htm>
  - List of structural plastics that are used in underwater vehicles:
    - PVC (Polyvinyl Chloride) – a polymer of vinyl chloride used especially for electrical insulation, films, and pipes
      - Polyvinyl chloride is the third most widely produced plastic, after polyethylene and polypropylene.
      - Popular for use in shallow water ROV (Remotely Operated Vehicle) and AUV (Autonomous Underwater Vehicle) designs
      - Readily machined (at slow speeds to prevent melting)
      - Easily joined together with glue
      - Not used for major structural members due to brittleness, especially in deep waters with low temperatures

- ABS (Acrylonitrile-Butadiene-Styrene) – Copolymer with great strength and rigidity that is used in pipe and fittings for sanitary and storm drainage, car bodies, and cases for computers and other appliances
  - A durable and impact resistant plastic. If struck, it will dent or break, but will not shatter like PVC.
  - Material can be bonded with solvents or attached to itself with ultra-sonic or heat welding methods.
  - Easy to machine; can be machined similar to woods or soft metals (brass)
    - One of the few problems in machining ABS is chip reweldment. This occurs when the chip is not removed properly or quickly enough. It can also occur when the feed rate is too slow.
  - FDA compliant with food
  - Foamy internal surfaces make it difficult to machine smooth surfaces, such as those required to seat O-rings.
  - Can be used in shallow water ROV and AUV projects
- Polycarbonate (Lexan) - any of a class of thermoplastics characterized by high-impact strength, light weight, and flexibility, and used as shatter-resistant substitutes for glass
  - Significantly stronger than plate glass and acrylic
  - Due to its excellent insulating properties, polycarbonate is energy efficient, especially in comparison with glass of equal thickness.
  - Allows up to 88 percent of visible light to pass through
  - Provides proven resistance to both physical and ballistic attacks
  - Polycarbonate sheets are more prone to scratching because polycarbonate is soft in comparison to acrylic.
  - Can undergo large plastic deformations without cracking or breaking - even for sharp angle bends with a tight radius, no heating is generally necessary.
  - Can be solvent bonded
- Acetal (Delrin) – An engineering thermoplastic. Used in precision parts due to its high stiffness, low friction, and excellent dimensional stability. Commonly known under DuPont's trade name Delrin.
  - Excellent machining
  - Low coefficient of friction
  - Very low moisture resistance
  - Naturally self-lubricating
  - Injection molding is the most common method for processing acetyl.
  - Good for bearings, gears, and other moving parts in corrosive environments

- Acrylic (Plexiglas) – A transparent thermoplastic. Can be cast, molded, or used in coatings and adhesives.
      - Transmits up to 92% of visible light (3 mm thickness)
      - Used for tunnels in aquariums, for the window of the bathyscaphe Trieste, in the lenses of exterior lights of automobiles, and for spectator protection in ice hockey rinks among other uses
      - Strong, lightweight, and more resistant to impact than glass
      - Is more prone to scratching compared to conventional inorganic glass
      - Highly weather and chemical-resistant
      - Behaves in a brittle manner when loaded, especially under an impact force
      - Machineable and heat-bendable
      - Can be solvent bonded
      - Can be used for canisters for up to 10 meters deep in water
      - Not used for frame material
      - Develops crazing, which is a network of fine cracks on the surface of a material. Crazing is a phenomenon that frequently precedes fracture, giving an early warning of failure. It is typified by a whitening of the crazed region. The white color is caused by light-scattering from the crazes.
  - Perform Structures and Materials Lab 4 – Working with Plastics
- **Other Structural Materials:**
  - Glass: Used less than acrylic for viewports and camera ports because it shatters easily upon impact and the fabrication costs for glass-to-steel ports are high
  - Glass-Reinforced-Plastics (GRP) or fiberglass – Manufactured by pulling random lengths of molten glass into filaments, which are then gathered into a wool-like mass or formed into continuous threads. These filaments are then embedded in resins to make boat hulls, fishing rods, car bodies, etc.
    - An example of composites which are made by embedding strands of one substance into another to produce structural or functional properties not present in any individual component. The strands used for this purpose can be glass, carbon, or Kevlar.
    - Very high strength-to-weight ratio
    - Excellent corrosion resistance
    - Tough: able to withstand great strain without tearing
    - Inexpensive
    - Easy to fabricate, but precautions must be taken to ventilate work areas and to avoid skin and respiratory exposure

- **Metal Corrosion:** See textbook
- **Corrosive Environment in a Swimming Pool:**
  - Disinfecting chemicals deteriorate rubber and various metals
    - Rubber will lose its elasticity and become brittle. This is especially true if the pool is exposed to sunlight.
    - Aluminum corrodes in pool water treated with chlorine or bromine.
    - To prevent harm to rubber and metals, wash the ROV after removal from the pool and store out of direct sunlight.
  - pH also contributes to the deterioration of metals. A pool that is too acidic will corrode aluminum and carbon steels.

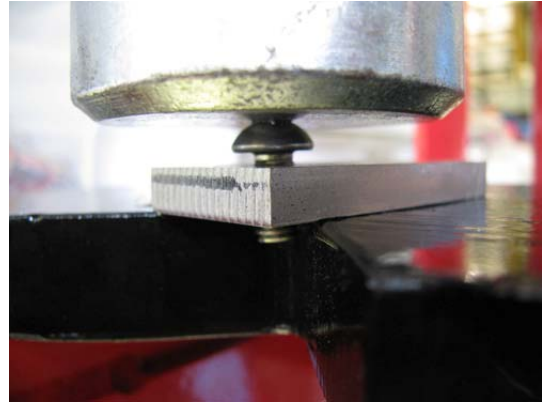
## Cornerstone Electronics Technology and Robotics III Structures and Materials Lab 3 – Working with Metals

- **Purpose:** In order to obtain firsthand knowledge of the machining properties of each metal, students will drill, cut, tap, and mill several different metals.
- **Apparatus and Materials:**
  - 1 – [10-Ton Hydraulic Bench Press with Pressure Gauge](http://www.northerntool.com/shop/tools/product_200332763_200332763?cm_ite=145208&cm_pla=Metal%20Fabrication%3EShop%20Presses&cm_cat=Shopping&cm_ven=Aggregates)  
([http://www.northerntool.com/shop/tools/product\\_200332763\\_200332763?cm\\_ite=145208&cm\\_pla=Metal%20Fabrication%3EShop%20Presses&cm\\_cat=Shopping&cm\\_ven=Aggregates](http://www.northerntool.com/shop/tools/product_200332763_200332763?cm_ite=145208&cm_pla=Metal%20Fabrication%3EShop%20Presses&cm_cat=Shopping&cm_ven=Aggregates))
  - 1 – ¼" x 1" x 3" 6061 Aluminum Rectangular Bar from MSC:  
<http://www1.mscdirect.com/cgi/NNSRIT2?PMAKA=32012254&PMPXNO=1854656&cm>
  - 1 – ¼" x 1" x 3" Naval Brass 464 Rectangular Bar from MSC:  
<http://www1.mscdirect.com/cgi/NNSRIT2?PMAKA=32002347&PMPXNO=1853745&cm>
  - 1 – ¼" x 1" x 3" Bronze Rectangular Bar from MSC:  
<http://metalworking.mscdirect.com/CGI/NNSRITW?PMPXNO=4451436>
  - 1 – ¼" x 1" x 3" 303 Stainless Steel Rectangular Bar from MSC:  
<http://www1.mscdirect.com/cgi/NNSRIT2?PMAKA=75275917&PMPXNO=8250220&cm>
  - Tapping Fluid from MSC:  
<http://www1.mscdirect.com/cgi/NNSRIT2?PMAKA=05651294&PMPXNO=1744995&cm>
- **Procedure:**
  - Evaluate each metal through the machining processes below. For each process, compose a list rating the easiest to the most difficult metal to work with.
  - Using a hacksaw, cut a 3" length from the stainless steel piece. Then use the band saw to cut a 3" length from each remaining metal. After completing all the cuts, compose a list rating the metals according to how difficult it was to cut them.
  - Mill the cutoff end of each piece. **Use the proper end mill for each material; ask the instructor.**
  - Using the **proper** #7 drill bit for the material, drill a hole into each of the metals.
  - Thread each piece with a ¼"x20 tap and tapping fluid. **Be careful not to break the tap.**

- Screw a 1/4"-20 x 1" stainless steel screw into the tapped hole until the head of the screw is approximately 1/8" off the metal surface. Refer to the Photo 1 below.



**Photo 1**



**Photo 2**

- With the hydraulic bench press, push the screw into the metal until the head of the screw is touching the surface of the metal. Record the maximum applied force it took to make the threads fail. See Photo 2.

● **Results:**

- Evaluate the drilling properties of each metal. Make a list from easiest to hardest metal to drill.
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
- Evaluate the tapping properties of each metal. Make a list from easiest to hardest metal to tap.
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
- Evaluate the cutting properties of each metal. Make a list from easiest to hardest metal to cut.
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_



- Compression test:

<b>Metal</b>	<b>Applied Force for Threads Failure (lbs)</b>
Aluminum	
464 Naval Brass	
Bronze	
303 Stainless Steel	

- **Conclusions:**

- Determine if there is any correlation between the results recorded in the thread failure list and the tapping list.

## Cornerstone Electronics Technology and Robotics III Structures and Materials Lab 4 – Working with Plastics

- **Purpose:** In order to learn firsthand the machining properties of each plastic, the students drill, cut, tap, and mill several different plastics.
- **Apparatus and Materials:**
  - 1 – [10-Ton Hydraulic Bench Press with Pressure Gauge](http://www.northerntool.com/shop/tools/product_200332763_200332763?cm_ite=145208&cm_pla=Metal%20Fabrication%3EShop%20Presses&cm_cat=Shopping&cm_ven=Aggregates)  
([http://www.northerntool.com/shop/tools/product\\_200332763\\_200332763?cm\\_ite=145208&cm\\_pla=Metal%20Fabrication%3EShop%20Presses&cm\\_cat=Shopping&cm\\_ven=Aggregates](http://www.northerntool.com/shop/tools/product_200332763_200332763?cm_ite=145208&cm_pla=Metal%20Fabrication%3EShop%20Presses&cm_cat=Shopping&cm_ven=Aggregates))
  - 1 – ¼"x1"x4" Clear Acrylic Plastic from MSC:  
<http://www1.mscdirect.com/CGI/NNSRIT2?PMPXNO=1987246&PMTERM=63389035>
  - 1 – ¼"x1"x4" Natural Color Acetal (Delrin) from MSC:  
<http://www1.mscdirect.com/CGI/NNSRIT2?PMPXNO=1987023&PMTERM=63386809>
  - 1 – ¼"x1"x4" ABS from MSC:  
<http://www1.mscdirect.com/CGI/NNSRIT2?PMPXNO=1928069&PMTERM=52419777>
  - 1 – ¼"x1"x4" Polycarbonate (Lexan) from MSC:  
<http://www1.mscdirect.com/CGI/NNSRIT2?PMPXNO=1988886&PMTERM=63405435>
  - 1 – ¼"x1"x4" UHMW-Polyethylene from MSC:  
<http://www1.mscdirect.com/CGI/NNSRIT2?PMPXNO=1929276&PMTERM=52431921>
  - 1 – ¼"x1"x4" Fiberglass
- **Procedure:**
  - Evaluate each plastic through the machining processes below. For each process, compose a list rating the easiest to the most difficult plastic to work with.
  - Using the band saw, cut a 4" length from each plastic
  - Mill the cutoff end of each piece. Use the proper end mill for the material.
  - Using a #7 drill bit, drill a hole into each of the plastics.
  - Thread each piece with a ¼"x20 tap.
  - Screw a ¼"x20x1" stainless steel screw into the tapped hole until the head of the screw is approximately 1/8" off the plastic surface.
  - With the hydraulic bench press, push the screw into the plastic until the head of the screw is touching the surface of the plastic. Record the maximum applied force it took to make the threads fail.

- **Results:**

- Evaluate the drilling properties of each plastic. Make a list from easiest to hardest plastic to drill.

- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

- Evaluate the tapping properties of each plastic. Make a list from easiest to hardest plastic to tap.

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- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

- Evaluate the cutting properties of each plastic. Make a list from easiest to hardest plastic to cut.

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- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

- Compression test:

Plastic	Applied Force for Threads Failure (lbs)
Acrylic	
Acetal (Delrin)	
ABS	
Polycarbonate (Lexan)	
UHMW-Polyethylene	
Fibreglass	

- **Conclusions:**

- Determine if there is any correlation between the results recorded in the thread failure list and the tapping list.