MANU2482 - Material Engineering

Group Project - Material Selection for Engineering Application

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TEAM CONTRIBUTION AND REFLECTION

Member name	Work contribution	Work contribution in words
Truong Tan Gia Huy	20%	Provided report format, checked and corrected the errors, and did editing.
Nguyen Bao Tuan	20%	Worked on buoyancy, material analysis of Ti6Al-4V and manufacturing process, evaluate and write the executive summary.
Nguyen Mau Tung	20%	Finding and calculating cost for all three alternative materials, checking and recalculating the errors for formula values. Checking and rewriting format errors.
Le Duc Huy	20%	Design the model for submersible; analyse and sum up selected materials into matrix; write conclusion; work on the engineering review and recommendation.
To Hung Phuoc	20%	Research the environmental and design requirements; work on the design background and objectives; work on the HY80 and HY100 steel alloy materials.

1. EXECUTIVE SUMMARY

This report will analyse the material selection procedures and investigate the considerations of failure prevention and environmental degradation in deep sea conditions. In this project, the conditions under water create many factors such as pressure, salt water and temperature that affect the materials. Material selection procedures are important because selecting a suitable material base on requirements mean that the product can have reliable stability and non-degradability. Our job is to identify the requirement of the applications and conditions, then translate it into a material specification and propose a new suitable engineering material which can endure the hazardous environment.

2. DESIGN PROBLEMS AND OBJECTIVES

2.1. Background

The case of submarine called Titan (designed and built by OceanGate Expeditions), which was first put in operation on June 19, 2023. The submarine mission on that day was to transport tourists to see the wreckage of Titanic. But when it dives to the depth around 3500m, the pressure hull imploded. The reason for implosion is while the submarine descending toward Titanic wreckage, the enormous pressure from surrounding water apply to the Titan's hull and it failed to hold out against the pressure. The entire submarine's hull is made from 13cm thick carbon-fibre composite wall which was designed to withstand the depth of 4000m [1,2,3,4].

Figure 1: The Titan Submarine of OceanGate

Firstly, we should go through the main concept of submarine, how it is created, the way how it functions, and requirement of materials needed to build ships. Submarine is the type of boats which are built to travel down into deep water. It was created in 19th century, which was widely operated in military purposes to attack the enemy under ocean. Nowadays, submarine is developed to be more suitable in many applications, such as tourism, science, vacation, navigation and so on.

The main process to control submarine going under water is based on the important feature called Buoyancy. Buoyancy is hollow empty space that is placed at the bottom of submarine, which is also known as the ballast tank [5].

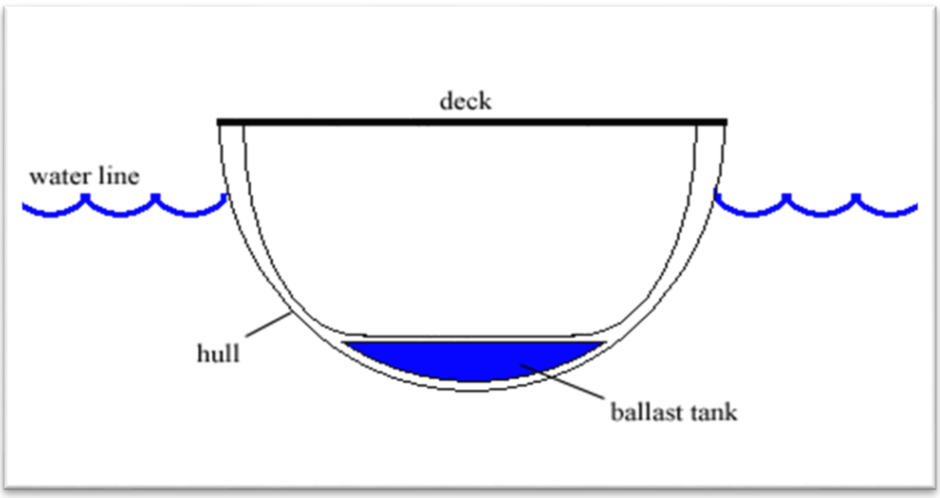

Figure 2: The ballast tank is placed at the bottom of boat

In order to allow the vessel to move under the water, buoyancy will allow the water to go in to be filled, which makes the overall weight of the submarine larger, so that it is denser than the density of water. Otherwise, to go up to the sea surface, the buoyancy will push the inside water go out, let the ballast tank in submarine more filled with air, so that is less weight than water. When under water, the submarine will function the propulsion system to move forward. There are many options of choosing the proper propulsion systems, which are depended mainly on the structure of submarine, the use of it, the economic management and so on.

The submarine Titan works similar to the methods mentioned above: using the buoyancy to control the overall density of the submarine, which floats or sinks, and electric propulsion system to control the direction.

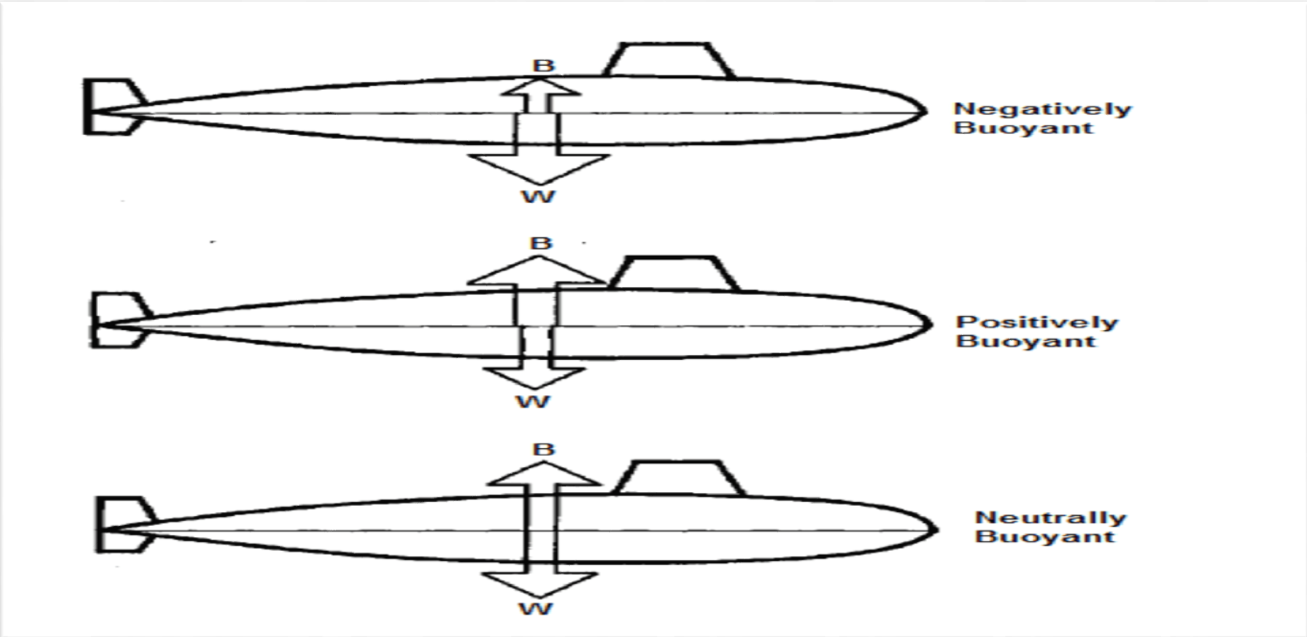

Figure 3: The overall weight of submarine depends on how empty of ballast tanks

The next important things to consider when starting building submarines is the material used to make. Many conventional submarines, or some ships nowadays are usually constructed by steel-alloy material due to its endurance of high-strength stress from deep ocean. The cover of submarines is coated to prevent the corrosion from the high-salt water.

In order to find out the suitable material for construction of submarine, we need to investigate the environmental hazard when submarines reaching deeper in ocean.

The submarine Titan was launched in North Atlantic Ocean, where lots of wreck of Titanic ships were frequently found. Therefore, we will estimate the condition of this specific ocean. Also, the additional requirement is that the submarine should be able to go at depth of X meters, which X is calculated by (X = (1 + 1 + 8 + 7 + 4)/5 * 1000 = 4200 meters).

2.2. Objectives

Main objective for this report is to improve the quality of the OceanGate submersible Titan by altering materials for the vessel while maintain the shape and dimension of Titan submarine, and based on the found information, we can analyse and prompt new material. The basic data about Titan is shown in the figure below.

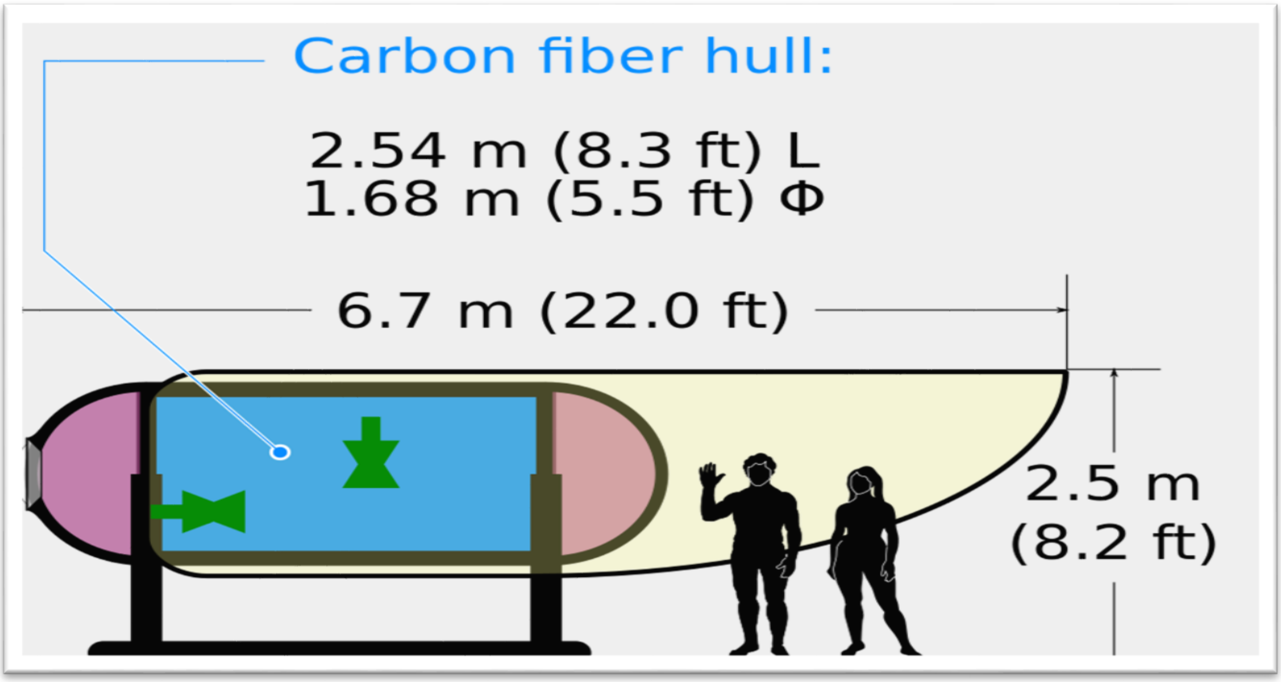

Figure 4: Schematic of Titan submarine, with figure of human

Titan is constructed using the titanium and filament wound carbon fibre, which we would replace them [3,4].

In general, our new designed submarine would be capable of satisfying these mentioned below conditions:

- Capsuled-shaped vessel, with the height of 2.5 meters, length of 6.7 meters, and width of 2.5 meters (volume 41875 litters) based on the size of beam [4]. The reason why the submarine is built in shape of vessel is to distribute the external force uniformly [6]. It is combined by many small sections that are tightly reinforced by ribs and bulkheads together to build the durable and resilient hull.
- Be able to contain up to 5 US normal grown-up people.
- Can travel underwater at speed about 1.54 meters per second.
- Be capable of enduring the high pressure at 4200 meters in deep of ocean.
- Prevent corrosion due to the high rate of salinity.
- Have redundant life-support system.
- Have enough oxygen for all crews during the journey.
- Buoyancy system can work effectively in fast sinking and floating.

3. PROJECT SPECIFICATIONS

There are many forces and stresses at the deepest area of the ocean appearing to apply into the submarine. These forces and factors will be listed out below and discussed so far. There are two main kinds of challenges: environmental challenges and design requirements. These two kinds of factors are not completely separate; it can somehow interact with each other. For example, the value of hydrostatic pressure can be used to obtain the minimum thickness of the submarine's hull. The weight of submersible is much less than in the air due to the buoyant force under the deep sea.

3.1 Environmental challenges

3.1.1 Extreme hydrostatic pressure

At such the lowest point of the ocean, the applied pressure on the submarine is the highest, which can be found by the formula: P = h * g * rho [7]. The term h is the depth of submarine up to the surface, rho is the density of the water, and g is the acceleration of gravity, which is usually assumed as 9.8 m/s^2. The density in North Atlantic Ocean is found to have value around 1025 kg/m^3 [7].

Therefore, the pressure is about P = 1025 kg/m^3 * 9.8 m/s^2 * 4200 m ≈ 42,441,600 Pa, which is considered very large amount. Even though the value of pressure is varying based on the temperature of the ocean, the rate of salinity, and the speed of fluid flow, the amount of the pressure is still significantly high. In addition, there are atmospheric pressure and gravity that exist affect onto the hull of submarine, so they need to be included.

Another impacts that need to be considered is the shock load happening above the submarines. Shock loads usually exist due to the instant explosion of gas bubbles in every part of ocean. This would cause to create many shockwaves at the top of ships, which eventually drags the submarines down to below the operated depth. Therefore, we need to increase the design hydrostatic pressure for safe conditions. The new value is assumed around 45,000,000 Pa.

3.1.2 Electrochemical Corrosion due to the salt water

The North Atlantic Ocean is known for having high rate of salinity [8], which is estimated exceeding 37 ppt. That means it would damage any metals over five times faster than fresh water. The moisture, combined with oxygen in the atmosphere and salt in ocean can destroy any metals in short period of times, which causes it weaker and make it easily crack and fail. Every corroded part of the hull can be very brittle, even though the material is a ductile type [9].

3.1.3 Low temperature

Low temperature can indirectly lead to many tremendous consequences affecting to submarine. Firstly, cold water can affect the materials by changing its properties. Extreme low temperature can transmit the material from ductile property into brittle ones, which increase the chances of fracture of submarine. This would impact badly a lot on hulls, vessel of the ships. The average temperature of the North Atlantic Ocean is around 25°C at the surface, but at the depth of 4200 meters, the temperature is much lower, around 2°C to 4°C, and it is nearly close to 0°C in winter, because of the lack of heat from sunlight and slow speed of fluid at the depth of ocean [10]. Secondly, cold water can increase the density of water, which may also increase the hydrostatic pressure applying on the submarine. It can affect the speed of fluid flow as well, so that the submarine will have more difficult to move underwater.

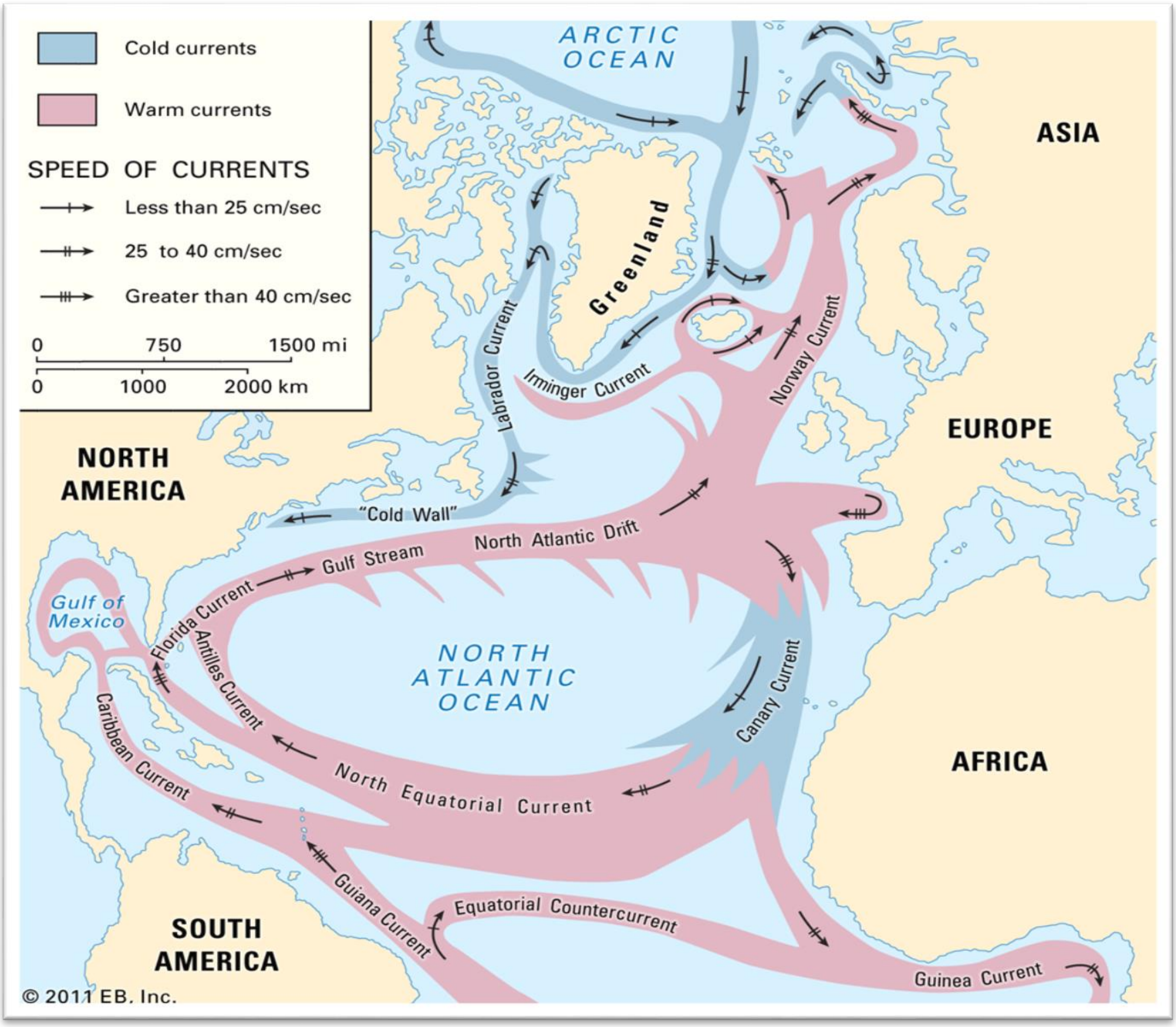

Figure 5: Major currents in North Atlantic Ocean (reason why water temperatures is cold)

3.1.6 Biological environment– negligible

High depth part of ocean is the home to many organism and kind of fish. If it is carefully examined before taking off, the journey will get easier to reach.

3.2 Design Requirements

3.2.1 Fracture prevention

The surface defects, or internal flaw can increase the risk of cracking of the materials. That is because the external stresses 'value will be multiplied by many times when affecting at that flaws, which easily leads the submarines to failure. There are no options to make material perfect, result in several flaws in the body. However, the chances of leading to fracture due to theses flaws can be effectively minimized. There are three following main components that should be considered when selecting the proper materials: the value of the fracture toughness of the material, the designed stress on the objects, and the acceptable size of the flaw [11].

It is researched there is the inverse-ratio relationship between the strength and the fracture toughness. The more strength that the materials can endure, the less it can be able to withstand the failure due to the fracture occurrence. Luckily, we can increase the thickness of wall and hull to decrease the value of fracture toughness. Therefore, it is assumed the thickness of submarine is growing to be much larger than value of crack size, until it is satisfied to apply the Plane Strain Fracture Toughness formula [12].

Using the Fracture Toughness Equation to find the value for tolerable size of crack a : $K_{ic} = Y * \sigma * \sqrt{\pi * a}$

The value of Y is identified based on the shape of the defects. If it has a circular edge, or it is penny-shaped, the Y is equal to $\frac{2}{\pi}$. If it is semi-infinite, Y is 1.12; and Y is 1 when the flaw is infinite plate. In this report, we would design in the worst-case scenario, so the value of Y would be 1.12 [13].

3.2.2 Structural Design of submarine

The construction design of a submersible plays an important role in enduring the extreme condition of the high-deep ocean. The hull of submersible must be designed to have a shape like cylindrical, or spherical, or capsule vessel, in order to distribute the load uniformly. In addition, the body parts are assembled together by strong reinforced components like bulkhead, or high-strength bolts or welding.

The minimum required thickness is examined as well. It can be figured out by the below formula:

$$minimum\ thickness = \frac{hydrostatic\ pressure * radius\ of\ hull}{2 * yield\ strength\ of\ used\ materials}$$

The hydrostatic pressure is computed above as 15 MPa, the radius of hull is assumed to be equal to the that of submersible Titan, which is 0.84 meters (= 1.68/2 meters). The remaining unknown values are thickness and yield strength value of materials. The thickness of Titan submarine is 5.1 inch, which is 130 millimetres (= 0.130 m). So the needed value of yield strength is around 55 MPa. However, we can change these two values accordingly. These can be modified in the part 5 of this report.

Safety factor should be considered as well. The average value of safety factor when constructing submarine is 1.5 compared to design requirements. Whereas, in some cases, the safety factor can be increase to 2.5, allowing the ships can sink lower than the required depth in bad conditions [14].

3.2.3 Design of Buoyancy

To control the buoyancy, the submersible can float or sink by filling the ballast tank with air or water. When the ballast is filled with water, its density will more than density of water and make the submersible sink. When the ballast is filled with air, its density will be less than density of water and make the submersible float.

For the submersible to sink, the downward force by the submersible weight due to gravity must be bigger than the upward force by the buoyance force. Buoyant force formula:

B (N) = ρ_f (kg/m^3) * Vρ_f (m^3) * g (N/kg) [30]

B = 1025 (kg/m^3) * 41.875 (m^3) * 9.81 (N/kg) = 421063 (N)

With rough calculation, the mass of the submersible Titan when carrying 5 people is around 10000 kg. So the weight of the submersible in the air is calculated by the formula [5]:

Weight (N) = m (kg) * Gravity (N/kg)

W = 10000 kg * 9.81 N/kg = 980000 (N)

The force from weight of submersible must be bigger than the buoyant force for the submersible to submerge W (980000 N) > B (421063 N) => The submersible will always sink. In order to make it float, it needs to fill the ballast with air to combat with water density.

3.2.4 Speed of submersible (including the resistance from the sea)

For the purpose of sightseeing, the submersible needs to go slowly. So, the design speed is same as the Titan submersible, which is 1.54 meters/second when under deep-sea conditions [4]. The compressive force on the submersible while moving is still primarily from hydrostatic pressure.

3.2.5 Enough supplier for 5 people

The submersible needs people to sit down rather than standing straight up, so it requires less space. In addition, the single seat for one person is assumed to be about 60 cm, which is quite comfortable if the passenger is not fat. Therefore, for 5 people in total, the submersible needs to be 300 cm long, with a separate chair for driver. The length of hull of Titan submersible is updated.

The sufficient oxygen for one normal people to breath in a day is about 550 litters of pure oxygen. So for five average US people the total pure oxygen is 550 litters x 5 = 2750 litters. Oxygen can be provided to occupants through pressurized container or generated by the oxygen generator. The supplier of oxygen will release the air in interval of time, or when there is a sign of decreasing oxygen [38].

In addition, there is a system to reduce the rate of carbon Dioxide in submersible, which is called "scrubbers". This is the device consisting of two different chemicals, which are sodium hydroxide and calcium hydroxide. These chemicals will react to the carbon dioxide exhaled from passengers and remove it after the chemical reaction [38].

4. ENGINEERING SPECIFICATIONS

The total stress must be included with the pressure from the atmosphere. Therefore, the theoretical pressure is:

$$Theoretical\ pressure\ =\ atmospheric\ pressure\ +\ hydrostatic\ pressure$$

$$=\ 101\ kPa\ +\ 45000\ kPa\ =\ 45101\ kPa.$$

If it is considered with the SF = 2.5, then the total designed stress is: theoretical pressure * 2.5 = 112752.5 kPa. So, the designed stress is around 113 MPa.

The ductile-to-brittle transition temperature is less than 2°C, so that it cannot be changed its property when the temperature of cold water is getting lower. The flaw size must be smaller than the acceptable theoretical value a. The material should be coated outside to prevent the corrosion and fatigue when exposed to deep ocean for long periods of time.

In conclusion, our new material should be strong, robust and durable enough to adapt these requirements:

- The submarine shall be able to withstand the compressive load at least of 113 MPa.
- The outer layer of the ships must be coated to prevent corrosion (if necessary).
- The service temperature has the minimum value less than freezing point of water 0°C.
- Any flaw size on the body of hull must be less than the tolerable value a (which will be found out in each of option below).
- Additionally, the structural design is in shape of cylinder, because this kind of form can help divide the pressure equally. The thickness should satisfy the requirements according to the provided above equation K_{ic}. Another dimensions of submersible would be the same of the Titan submersible [4, 15].

5. MATERIAL FITNESS ANALYSIS

To select the suitable materials, we need to consider many factors. Because the submersible needs the ductile materials to handle the corrupt force applied from deep sea many times, the Ceramics materials is cancelled out, which is considered very brittle [28]. Then, the Composite materials are not chosen as well, because it cannot endure the high compressive force [29]. The Polymers materials are known for having lower high fracture toughness than metals, which is a very crucial factor in constructing submersible. Therefore, we need to select the Metal materials. Based on the provided information, we finally conclude three best materials to be used all the time in submarine construction.

4.1 Option 1: HY-100 steel alloys

HY-100 steel alloys are the high-strength low alloy, which consists of the high percentage of Iron (Fe) element, which is 96.2%, and the rest are Nickel, Copper, Chromium and so on [16]. The small percentage of Chromium and Nickel play a very crucial role in helping this material resist the corrosion [17]. The density of this material is 7.87 g/cc. Due to its high-strength endurance, HY-100 steel alloys is reviewed to be one of the best options in submersible construction. It is estimated the compressive strength of materials is at least 689 MPa [18], which is 5.8 times larger than required value. Moreover, the fracture toughness of HY-100 is considered to have a good prevention to crack growth and very low growth of cycle failure.

Because there is no document about the value of fracture toughness of HY-100 at such a low temperature, it can be calculated based on the fracture toughness of Alloy steel 4340 at 260ºC, which is $50\ MPa\sqrt{m}$.

Material	Yield Strength MPa	Yield Strength ksi	K_{Ic} MPa$\sqrt{m}$	K_{Ic} ksi$\sqrt{in.}$
Metals				
Aluminum alloy[a] (7075-T651)	495	72	24	22
Aluminum alloy[a] (2024-T3)	345	50	44	40
Titanium alloy[a] (Ti-6Al-4V)	910	132	55	50
Alloy steel[a] (4340 tempered @ 260°C)	1640	238	50.0	45.8
Alloy steel[a] (4340 tempered @ 425°C)	1420	206	87.4	80.0
Ceramics				
Concrete	—	—	0.2–1.4	0.18–1.27
Soda-lime glass	—	—	0.7–0.8	0.64–0.73
Aluminum oxide	—	—	2.7–5.0	2.5–4.6
Polymers				
Polystyrene (PS)	25.0–69.0	3.63–10.0	0.7–1.1	0.64–1.0
Poly(methyl methacrylate) (PMMA)	53.8–73.1	7.8–10.6	0.7–1.6	0.64–1.5
Polycarbonate (PC)	62.1	9.0	2.2	2.0

Figure 6: Fracture toughness of some popular material in room temperature

Therefore, the flaw size is:

$$K_{ic} = Y * \sigma * \sqrt{\pi * a}$$

$$\Rightarrow 50 = 1.12 * 113\ MPa * \sqrt{\pi * a}$$

$$\Rightarrow a = 0.049\ (m)$$

⇒ With SF, the new value of a is: $a = \frac{0.049}{2.5} = 0.0196\ (m)$

Because we are in the lower temperature and HY-100 has higher yield strength, the value of the flaw size must be many times less than 0.0196 meters.

The BDTT of HY-100 steel alloys is found to be much lower compared to the required one, so it would satisfy the requirements.

Then, the next step is to determine the value of minimum thickness. It can be obtained by:

$$minimum\ thickness = \frac{hydrostatic\ pressure * radius\ of\ hull}{2 * yield\ strength\ of\ used\ materials}$$

$$\Rightarrow minimum\ thickness = \frac{113\ MPa * 0.84\ m}{2 * 689\ MPa}$$

$\Rightarrow minimum\ thickness = 0.0689\ (m)$ < the designed thickness of Titan.

Therefore, we can keep the same value of thickness of Titan submersible.

4.2 Option 2: Ti6Al-4V

The alloy is comprised of 90% Titanium, 6% Aluminum, 4% Vanadium is the most widely used of titanium alloys. The small percentage of Aluminum and Vanadium improves the hardness of the material. It has good weld ability, heat treatable, high strength and low density 4.42kg/dm^3 [19]. The surface of Ti6Al-4V produces a ceramic oxide layer that makes it resistant to salt water and highly acid environments [20]. The alloy has low thermal conductivity, which means that it transfers heat slowly, so it is a good insulator at 0°C [21].

From the graph of other alloy from Ti6Al-4V class, Yield strength is around 910MPa strong enough to withstand 113MPa compressive load, and fracture toughness is around 55 $MPa\sqrt{m}$ [22]. The flaw size is:

$$K_{ic} = Y * \sigma * \sqrt{\pi * a}$$

$$55 = 1.12 * 113\ MPa * \sqrt{\pi * a}$$

$$a = 0.06\ (m)$$

$$New\ a = \frac{a}{SF} = \frac{a}{2.5} = 0.024\ (m)$$

Because yield strength increases with decreasing temperature, the value of the flaw size must be less than 0.024 meters.

Then, the next step is to determine the value of minimum thickness. It can be obtained by:

$$minimum\ thickness = \frac{hydrostatic\ pressure * radius\ of\ hull}{2 * yield\ strength\ of\ used\ materials}$$

$$\Rightarrow\ minimum\ thickness = \frac{113\ MPa * 0.84\ m}{2 * 790\ MPa}$$

$\Rightarrow\ minimum\ thickness =\ 0.0600\ (m)$ < the designed thickness of Titan.

Therefore, we can keep the same value of thickness of Titan submersible.

4.3 Option 3: HY-80 steel alloys

Similar to option 1, HY-80 steel alloys are one of the most suitable candidate for building of submersible. It consists of the high percentage of Iron (Fe) element, but less than that of HY-100 which is 93.1%, leaving space for more element of Nickel, Copper, Chromium and so on. Therefore, this material can endure higher corrosion for the deep-sea ocean. The density is 7.75 g/cc, which is the heavy metals. The yield strength of HY-80 steel alloys is still considered to be very high. It is experimented the compressive strength of materials is 552 MPa, which is 4.9 times larger than required value. The process of finding the tolerable flaw size a is the same as in option 1, it can be calculated based on the fracture toughness of Alloy steel 4340 at 260ºC, which is $50\ MPa\sqrt{m}$. Therefore, the flaw size is:

$$K_{ic} = Y * \sigma * \sqrt{\pi * a}$$

$\Rightarrow 50 = 1.12 * 113\ MPa * \sqrt{\pi * a}$

$\Rightarrow\ a = 0.049\ (m)$

⇒ With SF, the new value of a is: $a = \frac{0.049}{2.5} = 0.0196\ (m)$

Because we are in the low temperature and HY-80 has higher yield strength, the value of the flaw size must be less than many times of 0.0196 meters. The BDTT of HY-80 steel alloys is lower than the freezing point water temperature, so it is acceptable [23, 24, 25].

Then, the next step is to determine the value of minimum thickness. It can be obtained by:

$$minimum\ thickness = \frac{hydrostatic\ pressure * radius\ of\ hull}{2 * yield\ strength\ of\ used\ materials}$$

$$\Rightarrow\ minimum\ thickness = \frac{113\ MPa * 0.84\ m}{2 * 552\ MPa}$$

$\Rightarrow\ minimum\ thickness =\ 0.0859\ (m)$ < the designed thickness of Titan.

Therefore, we can keep the same value of thickness of Titan submersible of 0.130 meters.

5. MANUFACTURING AND COST ANALYSIS

The submersible hull is made from multiple metal sheets. Firstly, the materials are selected. Then, the metal sheets are cut into desired sizes with acetylene torches that create a flame temperature around 2200°C [26]. This temperature is hot enough to burn through any Steel alloys or Titanium alloys material. Then they are rolled into shape by industrial grade rollers. Once the sheets are in the wanted shape according to the submersible design, they are welded together by using flux-cored arc welding to form the inner and outer hull or so called the ballast tank. The welding needs to make sure that it is watertight, and we can ensure this by doing Ultrasonic testing on all the welds [27]. Nowadays, a precisely controlled welding robot might replace manual welders for better consistency and quality welds.

Based on the current market price for the three following metal, their price are as follows:

HY-100 Steel Alloy: $500 - 630 / ton [31, 32, 33].

Titan Alloy Ti6Al-4V: $21.20 / Kg [34].

HY-80 Steel Alloy: is known as military grade steel so the price is much likely confidential, however, for Alloy Steels HY80 Plate, its price is $1.90 /lb [35].

And along with the weight of each design in different materials, which are evaluated by the Solidworks Software:

- HY100: 22253608.73 grams = 24.5304046119647 ton
- Titan: 12537238.68 grams = 12537.23868 kg
- HY80: 21940177.62 grams = 48369.8119084322 lbs.

Using the weight and price value $Price * Weight$:

- $\textbf{HY}-\textbf{100 Steel Alloy}: \$500 * 24.5304046119647\ \text{ton} = \$12265.202306$
- $\textbf{Titan Alloy Ti6Al}-\textbf{4V}: \$21.20 * 12537.23868\ \text{kg} = \$265786.46$
- $\textbf{HY}-\textbf{80 Steel Alloy}: \$\mathbf{1.90} * 48369.8119084322\ \text{lbs.} = \$91902.64263$

6. PERFORMANCE COMPARISON AND RECOMMENDATION

First of all, the table below is to summarised three selected materials based on the engineering criteria.

Table 1: Materials comparison

Engineering requirements	HY-100 Steel Alloy	Titan Alloy Ti6Al-4V	HY-80 Steel Alloy
1. Compressive High – strength endurance	689 MPa	910 MPa ⇒ The strongest materials	552 MPa
2. Minimum service temperature	Less than freezing point water temperature (-40°C to -60°C)	Less than freezing point water temperature less than -196°C) [36] ⇒ The Lowest DBTT	Less than freezing point water temperature (-40°C to -60°C)
3. Corrosion resistance	Not good, need coating in working environment	Excellence due to having the natural oxide out-layer. ⇒ The best prevention of corrosion	Not good, need coating in working environment
4. The minimum thickness	Satisfy the designed thickness of submersible.	Satisfy the designed thickness of submersible.	Satisfy the designed thickness of submersible.
5. Maximum allowable crack size	Much less than 0.0196 meters	0.024 meters ⇒ the maximum allowable size.	Much less than 0.0196 meters
6. Cost per hull	$12265.202306	$265786.46 ⇒ the highest price.	$91902.64263

Recommendation:

Based on the summary, the best suitable materials for submersible construction, in safety perspective, is Titan Alloy Ti6Al-4V. In the economical perspective, we can choose the HY-100 steel alloy or HY-80 steel alloys, because it is cheaper, but it has to be coated corrosion-resistant layer. In this case of report, the Titan Alloy is selected.

Moreover, the structural design also plays a crucial role in safety. It must be the shape of cylinder. The final design of our submersible is:

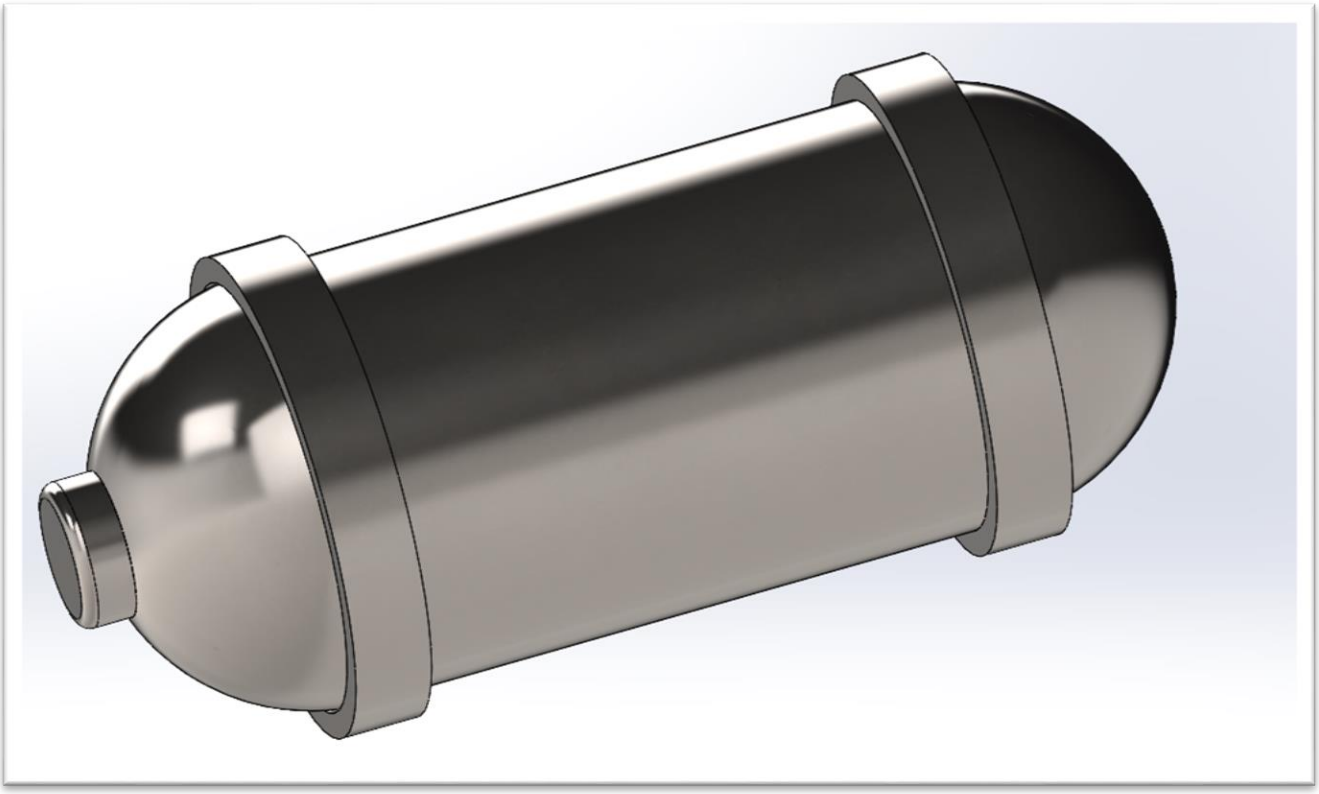

Figure 76: The overall design of the pressure hull of submersible in Solidworks

In addition, the submersible needs to be foamed outside layer. The type of foam that are used is the closed–cell foam, which has the ability not only to resist the water entering inside hull, but also to endure the high compressive strength [37].

The mass of submersible is now heavier, which is 12537.24 kg. Therefore, we have to create larger ballast tank to be suitable [30]. We also increase the speed of electric thruster to accommodate the required speed for sight-seeing purpose.

7. CONCLUSION

In conclusion, the final choice of materials for submersible construction is Titan Alloy Ti6Al-4V because it can satisfy all the engineering specifications above in working environment of North Atlantic Ocean with the highest efficiency. However, it still needs to be improved after several time doing experiments to make sure it is completely safe, efficient and reliable when it is put under high pressure conditions.

8. REFERENCE

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9. APPENDIX

OneDrive Link of Submersible built in Solidworks (we have shared it to email of lecturer **son.daovutruong@rmit.edu.vn**): Titan_submersible.SLDPRT.

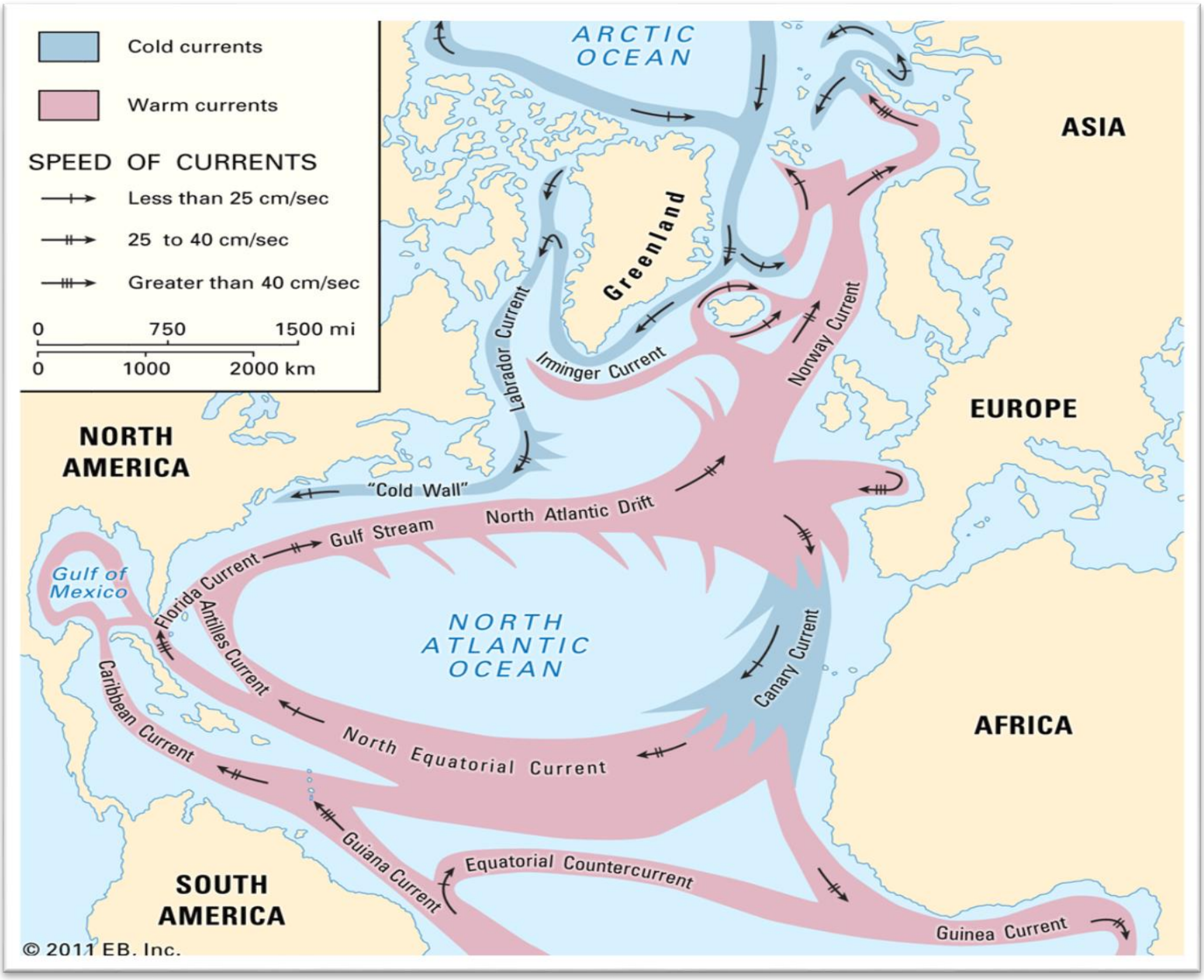

Figure 8: Major currents in North Atlantic Ocean (reason why water temperatures is cold)

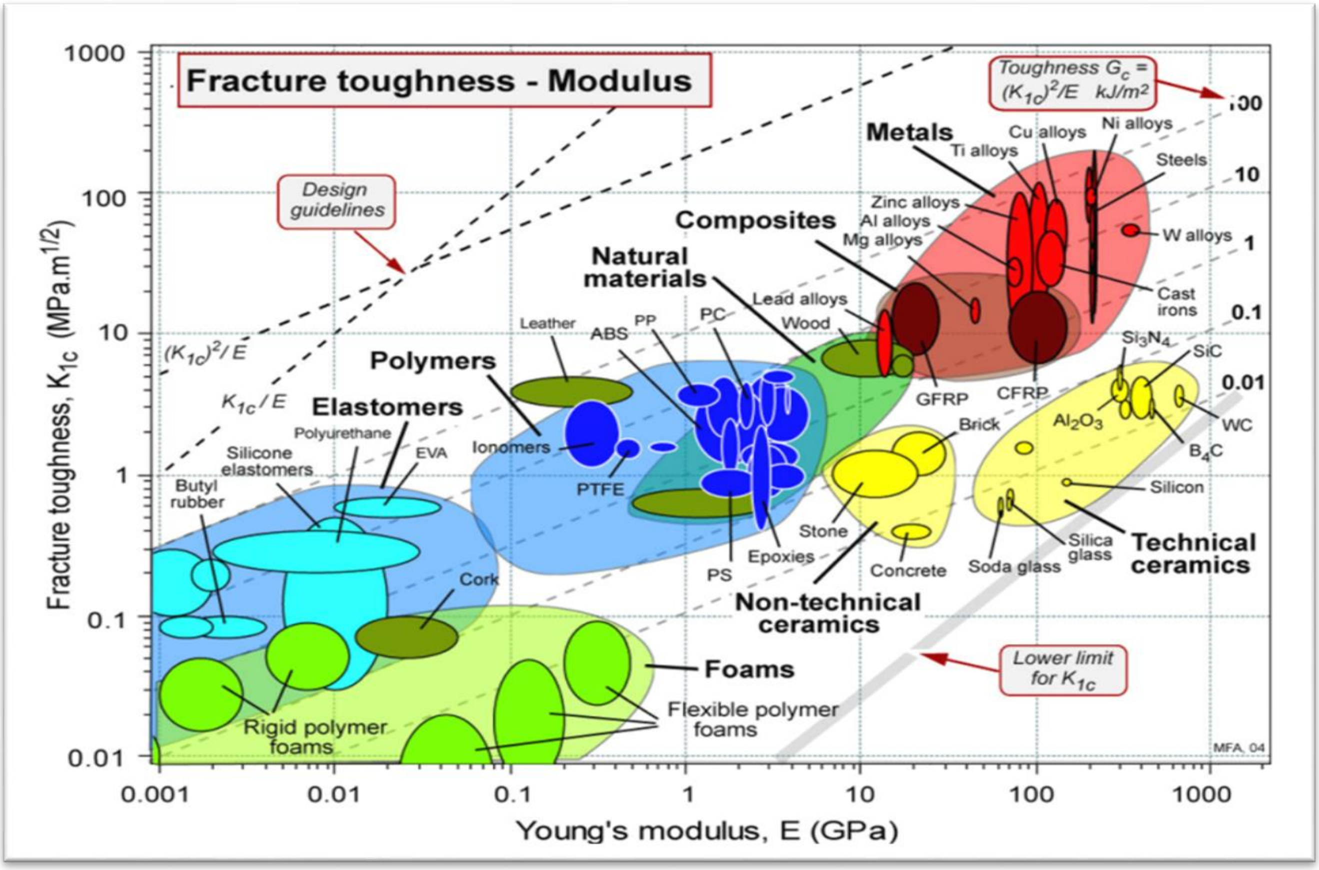

Figure 9: Graph showing Fracture Toughness Kic vs Young 's modulus E

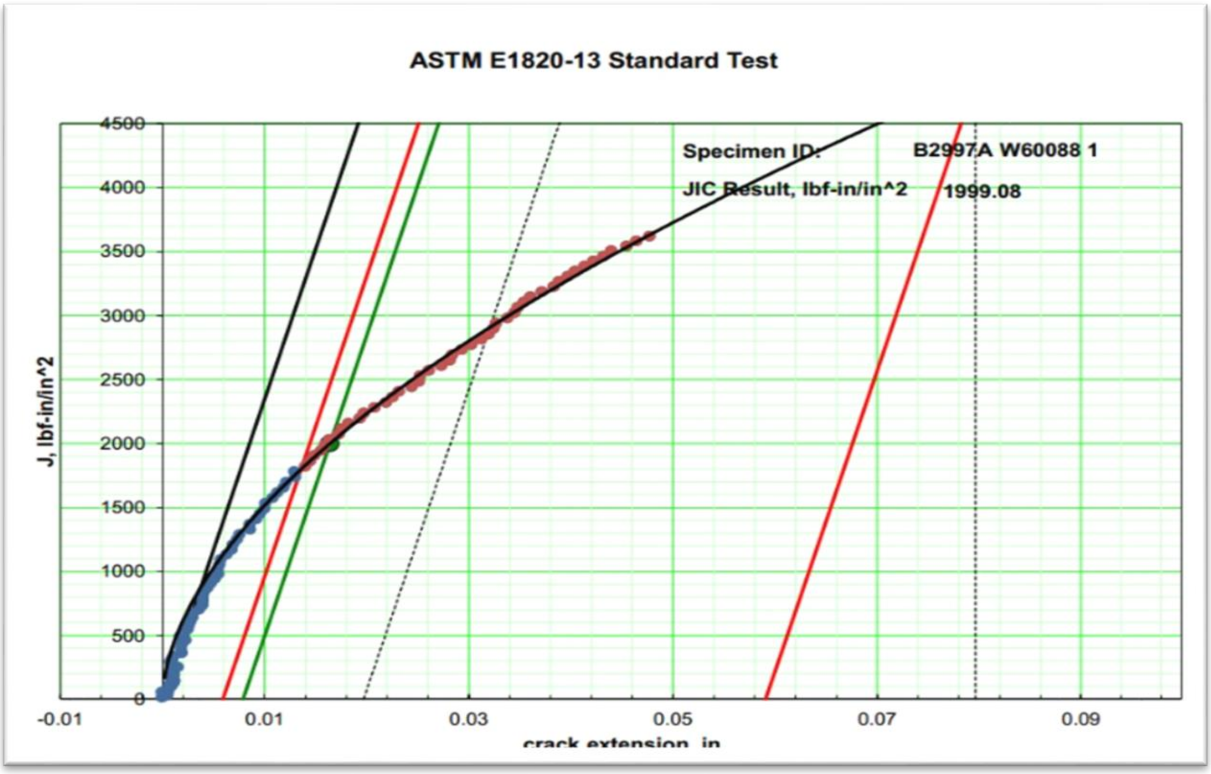

Figure 10: Result of the HY-100 steel alloy specimen in fracture testing experiment

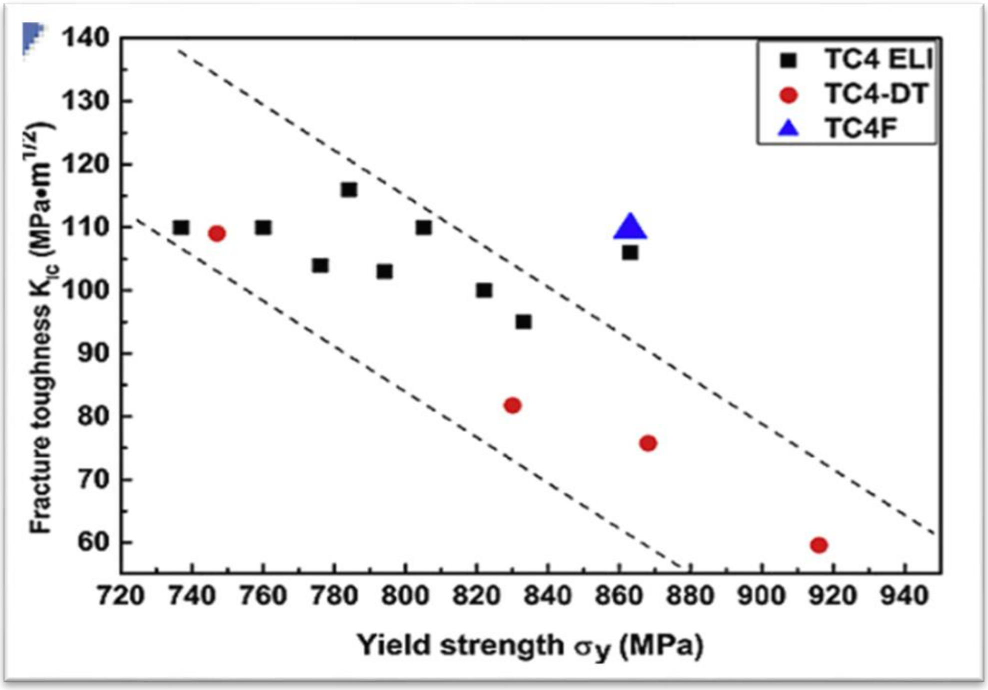

Figure 11: The fracture toughness of Titan Alloy Ti6Al-4V

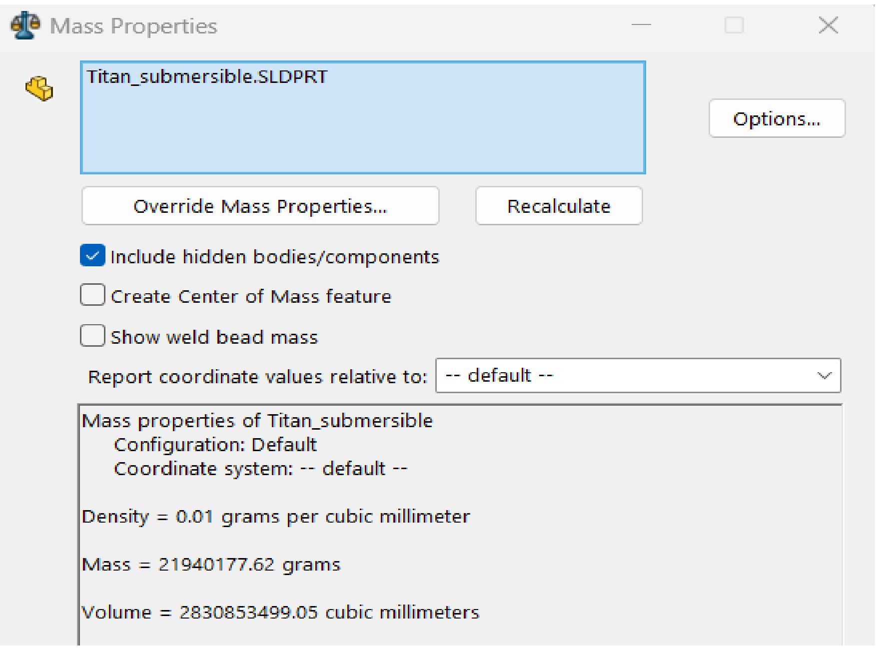

Figure 12: Properties of HY-80 steel alloys

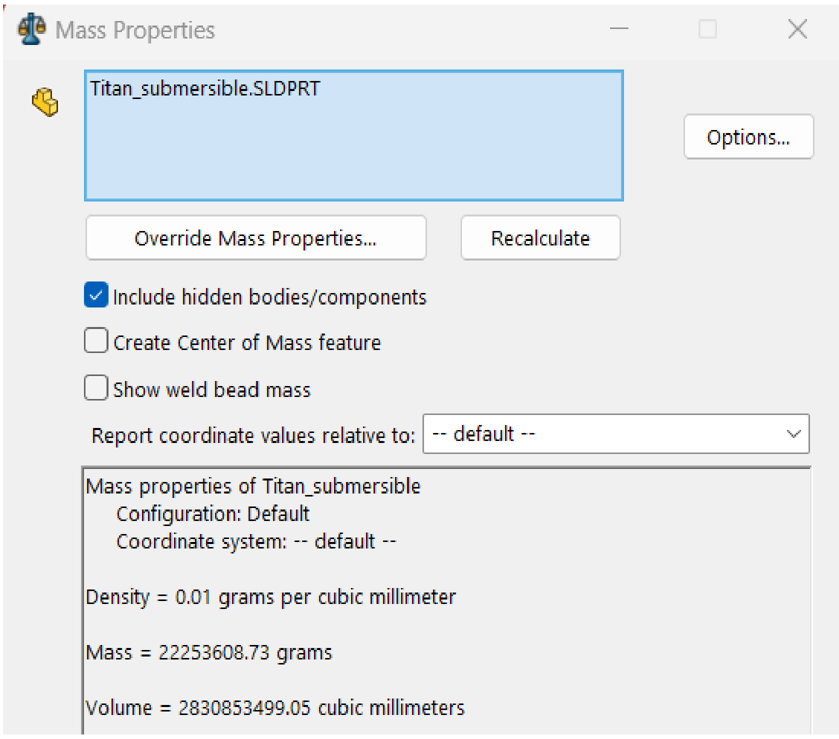

Figure 13: Properties of HY-100 steel alloys

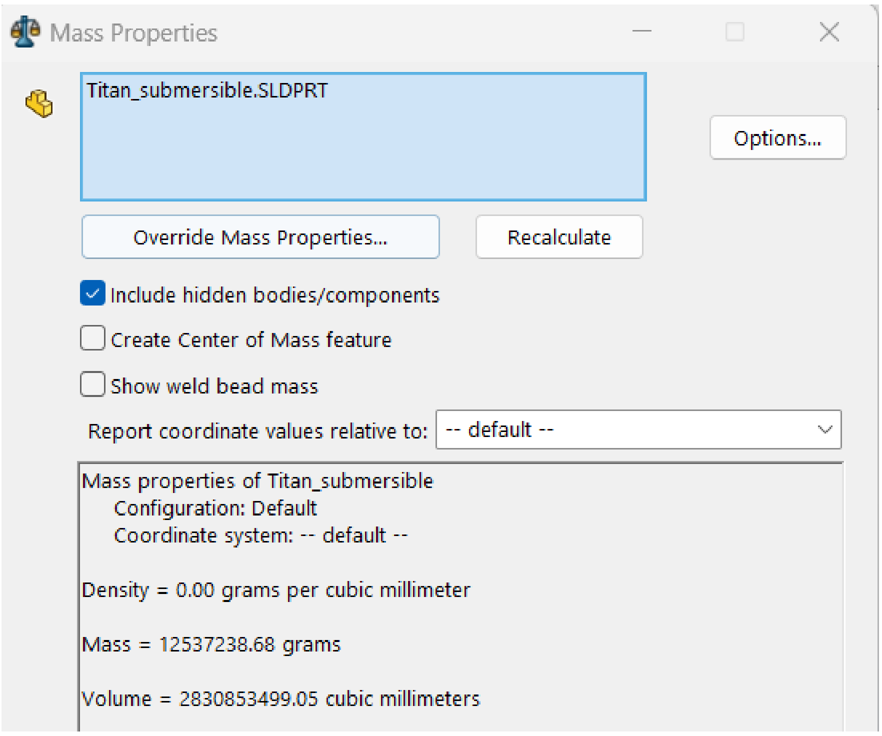

Figure 14: Properties of Titan Alloy Ti6Al-4V