Exploration of Materials for Scuba Fin Design using Ansys Granta EduPack

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Summary

Scuba diving is a captivating sport that involves underwater exploration using a Self-Contained Underwater Breathing Apparatus (SCUBA). Diving fins play a crucial role in facilitating efficient and enjoyable underwater swimming through foot-propulsion. Designing scuba diving fins requires meticulous attention to blade material selection, shape, and underwater kicking force and resistance. In this series of case studies, we will delve into the intricate world of scuba diving fin design. The focus of this particular case study will be on the identification of optimal material candidates. Systematic material selection methodology has been applied through Ansys Granta EduPack to visualize material properties and to screen and select proper material candidates for scuba diving fins. By thoroughly examining these crucial factors, students will gain a comprehensive understanding of how materials contribute to the overall performance and design of scuba diving fins.

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1. Introduction

Scuba diving as a sport is when a person dives underwater to explore nature with Self-Contained Underwater Breathing Apparatus (SCUBA). The typical basic SCUBA setup [1] includes a wetsuit or drysuit[1], gas tank, dive mask, regulator, Buoyancy Control Device (BCD), dive computer, and fins [2].

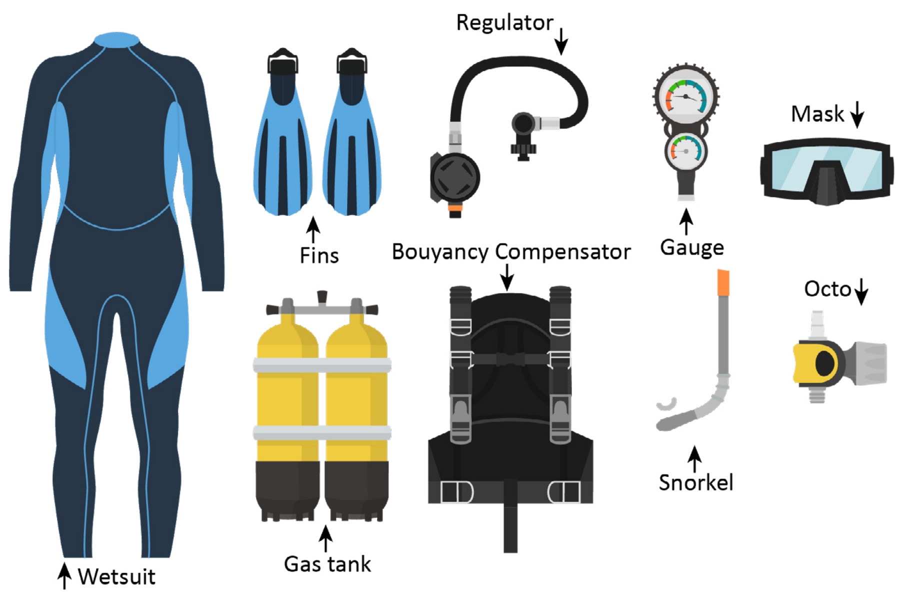

Figure 1: A typical basic SCUBA setup, including wetsuit, fins, snorkel, gas tank, and more

Years before SCUBA was invented, free divers and underwater hunters used fins with mask and snorkel to get down to depth quickly and provide bursts of speed as needed. Fins were created after observing the water-propulsion effectiveness of web-footed animals, such as ducks and frogs. Fins make swimming with foot-propulsion easier, more effective, and considerably more enjoyable.

Scuba divers have several needs when it comes to fins. Overall, scuba diving fins need to provide a balance of thrust, maneuverability, comfort, durability, and buoyancy in the right size to meet the specific needs of the individual diver and the conditions they are diving in. Here are some of the most important requirements:

- Propulsion: Scuba diving fins need to provide enough propulsion to move the diver through the water efficiently. This means they need to be able to generate a significant amount of thrust with each kick which requires stiffness.
- Comfort: Scuba diving fins need to be comfortable to wear which means they should fit well. They should avoid causing any chafing or discomfort while at the same time, fins that are too small or too large can negatively impact performance. To some extent, the flexibility and stiffness matter here as well.
- Durability and mechanical integrity: Scuba diving fins need to be able to withstand the stresses of regular use, including exposure to salt water and repeated impacts with rocks or other objects. Strength will be one of the crucial parameters in the sense that sports equipment must be strong enough to be safe for divers.

1 Wetsuits are skin-tight and used in other sports such as surfing. This suit keeps the wearer warm by heating up the layer of water in between the body and the suit. For extreme cold temperatures, a drysuit is needed. These are completely waterproof and have an air layer for additional thermal insulation.

• Buoyancy: The fins should not be too heavy, as this can negatively impact a diver's buoyancy control – this is governed by the materials density in relation to water.

• Maneuverability: Divers also need to be able to maneuver easily underwater, especially in tight spaces or strong currents. This requires fins with optimal stiffness that are responsive and easy to control, as well as precision in movements, which is important for divers who plan on diving in tight spaces or navigating through underwater obstacles.

To fulfill most (if not all) the requirements mentioned, designing scuba diving fins also requires careful consideration of the shape of the blades, the kicking force and resistance under water, as well as the materials that they are made from. Design requirements and design parameters can be explored via both material selection and simulation with Ansys software products. This content will be covered across two separate case studies; a breakdown of which requirements will be addressed in each document can be found in the table below.

Table 1 Breakdown of design requirements of the scuba diving fins using both material selection and simulation.

Ansys Tools Used	**Design Requirements**
Ansys Discovery	Shape of the blades, the kicking force and resistance under water: Propulsion, maneuverability, and size
Ansys Granta EduPack	Maneuverability, comfort and size, durability, and buoyancy

2. Materials selection background

In this case study, we will focus on exploring materials for scuba diving fins. We will examine the different materials options available for a balance/compromise between different needs for optimal performance. Maneuverability, durability, and weight are all related to materials. While scuba diving is considered an expensive sport, many participate on a budget and prioritize low cost, so this is an additional factor we need to consider: cost of the materials.

We will use Ansys Granta EduPack to conduct this exploration. It is a tool following the rational materials selection methodology by Ashby et al. [3], illustrated schematically in the diagram below.

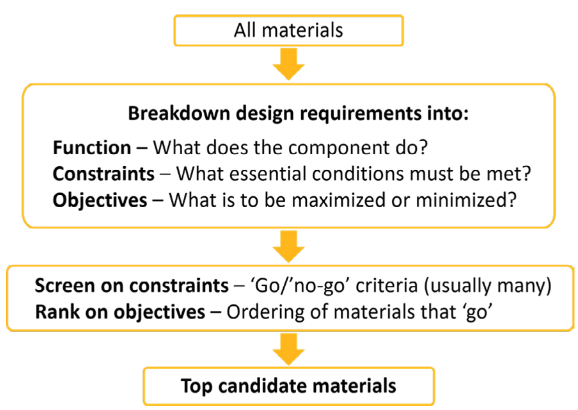

Figure 2: Systematic Materials Selection Methodology - a rational strategy for materials selection

To fulfill materials needs for scuba diving fins, we will focus on materials properties shown in Table 2. A balance between all these properties is essential for optimal performance, yet finding the right balance can be a challenge, as these properties often work against each other. For example, the fins need to be strong enough to withstand the forces of the water, yet flexible enough to provide the necessary propulsion and maneuverability. Different materials have different advantages and disadvantages, so designers need to carefully consider the specific requirements of the fins and select materials accordingly.

Table 2 Materials-related design requirements for scuba diving fins with their corresponding material properties

Materials-related design requirements	**Material properties**
Maneuverability	Young's modulus
Durability and mechanical integrity	Durability in water, saltwater, and marine atmosphere; yield strength
Buoyancy and weight	Density
Cost	Price

Finding the right balance between different material properties in scuba diving fins requires quite a bit of trial and error. With Granta EduPack, we will reduce the time and cost to do that.

3. Identifying material candidates with Ansys Granta EduPack

To fulfill the above-mentioned functions of scuba diving fins, our key objective for this case study will be to find affordable material candidates, which translate into minimize cost. As a result, the following constraints are considered in this case study:

1. Considering the usage scenarios, scuba diving fins need to be able to withstand exposure to water for pool and freshwater diving, saltwater, for sea water diving and marine atmosphere.
2. The fins must possess both strengths to endure water forces and flexibility and stiffness to ensure efficient propulsion and maneuverability.
3. All design dimensions are specified in this first part of the case study. We will consider the design in the second part of this case study using Ansys Discovery (coming soon).

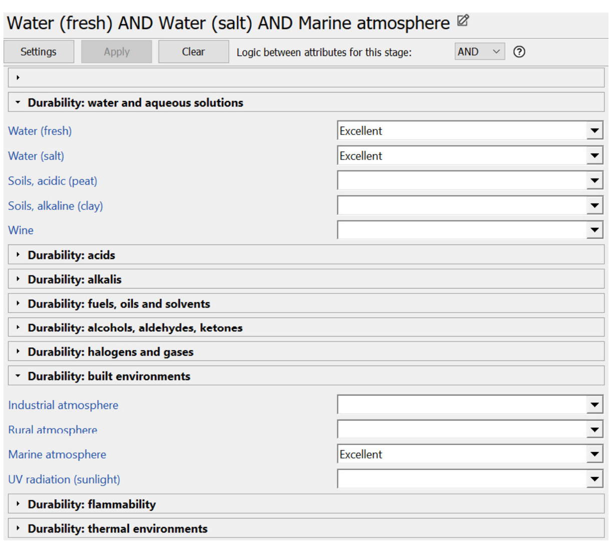

Figure 3: Durability in fresh water, salt water and marine atmosphere

For this case study, we will use Level 2 database with 100 engineering materials in Granta EduPack. To screen and find the top candidates for scuba diving fins, the Chart/Select tool is used, specifically, the Limit Stage for constraints, and the Chart/Index Stage for objectives and other discussion points. If you are not familiar with the Chart/Select tool yet, here are some Video Tutorials that will be of some help (Materials Learning - Ansys Learning).

After applying the durability constraints (Figure 3), excellent fresh water, and saltwater in marine atmosphere and durability, it brings down our candidates to over 50 engineering materials.

As mentioned, stiffness is contributing to propulsion and maneuverability, but this does not necessarily mean that we would look for materials with maximum stiffness in the case of scuba diving fins. Optimal or moderate, not maximum, stiffness would benefit the divers the most, since flexibility would affect the performance and comfort as well. To help us find materials with such stiffness, Figure 4 is a screenshot of Young's modulus ranges for all the 100 materials in the Level 2 database. We will bring our life experiences here to help us find materials proper for scuba diving fins: we all know rubber bands that are very bouncy and flexible made from natural rubber and polyurethane used in skateboard wheels which is more rigid and scuba diving fins seem to lie between this range comfortably. Accordingly, we will consider only materials with Young's modulus between these two materials for our exploration, according to Granta EduPack, between 0.00159 and 1.65 GPa.

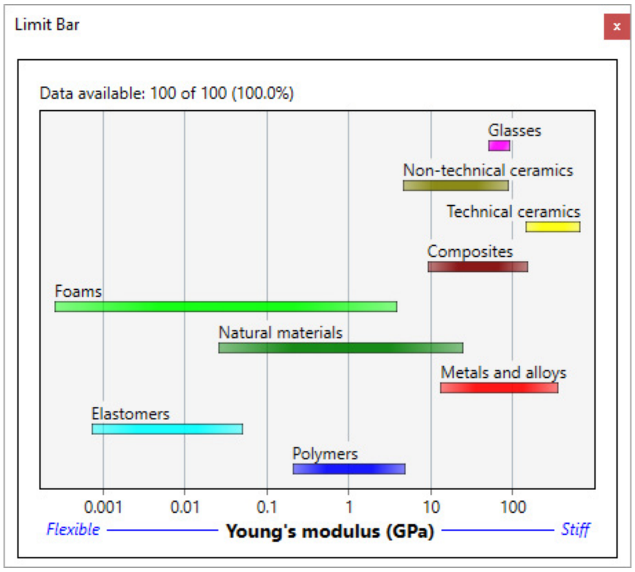

Figure 4: Young's modulus limit bar chart for all the 100 materials in Level 2 database

If we create a chart as shown in Figure 5, with a Box Selection tool, we are down from over 50 materials to 14 materials only with some polymers, elastomers, and foams left.

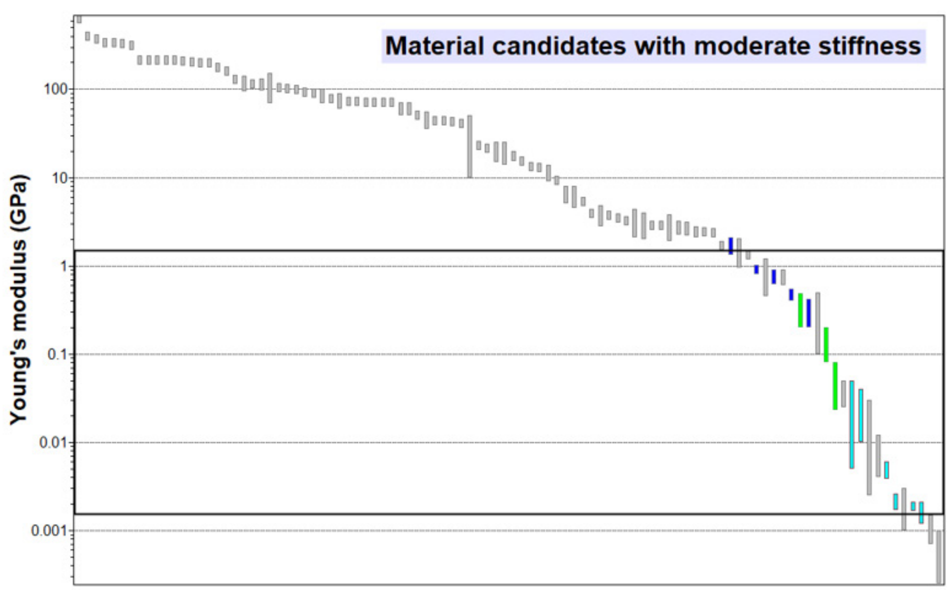

Figure 5: Material candidates with moderate stiffness for scuba diving fins

Our next step is ranking the 14 surviving candidates and to do that, we will introduce performance indices. In the Ashby materials selection methodology, a performance index is a ratio of material parameters to minimize or maximize the performance of a component, based on the specific function (load situation), limiting constraint, and objective of the design. For the scuba diving fins specifically:

- The function is the basic geometry and load condition of the design (e.g. for the scuba diving fin in use, it is most similar to a panel loaded in bending).
- The limiting constraint is the main property to be optimized for the component (for example, a stiffness-limited design, where a panel must not bend too much under an applied load or a strength-limited design, where a panel must not fail due to plastic collapse under an applied load. We will discuss both scenarios here).
- The objective is the main variable to maximize or minimize.
- The free variable is the geometry parameter that is free to vary with material choice (e.g. the thickness of a panel).

Each combination of function, limiting constraint, objective, and free variable has a characteristic performance index. For example, a light (objective), stiff (limiting constraint), panel loaded in bending (function), with thickness as the free variable, has a performance index of $E^{1/3}/C_m\rho$, where E=Young's modulus (limiting constraint for stiffness), C_m=price (objective for minimizing cost) and ρ=density (objective for minimizing mass). Similarly, a light (objective), strong (limiting constraint), panel loaded in bending (function), with thickness as the free variable, has a performance index of $\sigma_y^{1/2}/C_m\rho$, where σ_y=yield strength (limiting constraint for strength), C_m=price (objective for minimizing cost) and ρ=density (objective for minimizing mass). If you are not familiar with performance indices and how to derive them yet, Prof. Ashby's textbook, Materials Selection in Mechanical Design [3] and the following white paper (Materials Selection White Paper | Ansys) and booklet (Performance Indices Reference Booklet | Ansys) will be some good reading and reference resources.

In Figure 6 and Figure 7, we have plotted these two performance indices respectively.

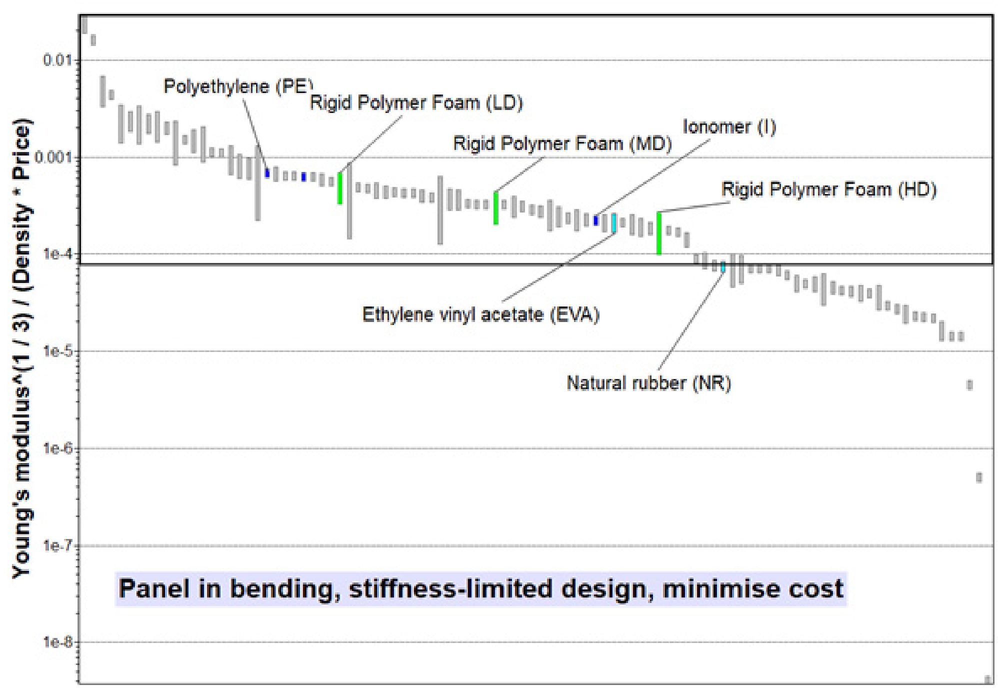

Figure 6: Scuba diving fins translated as panel in bending, stiffness-limited design, minimize cost.

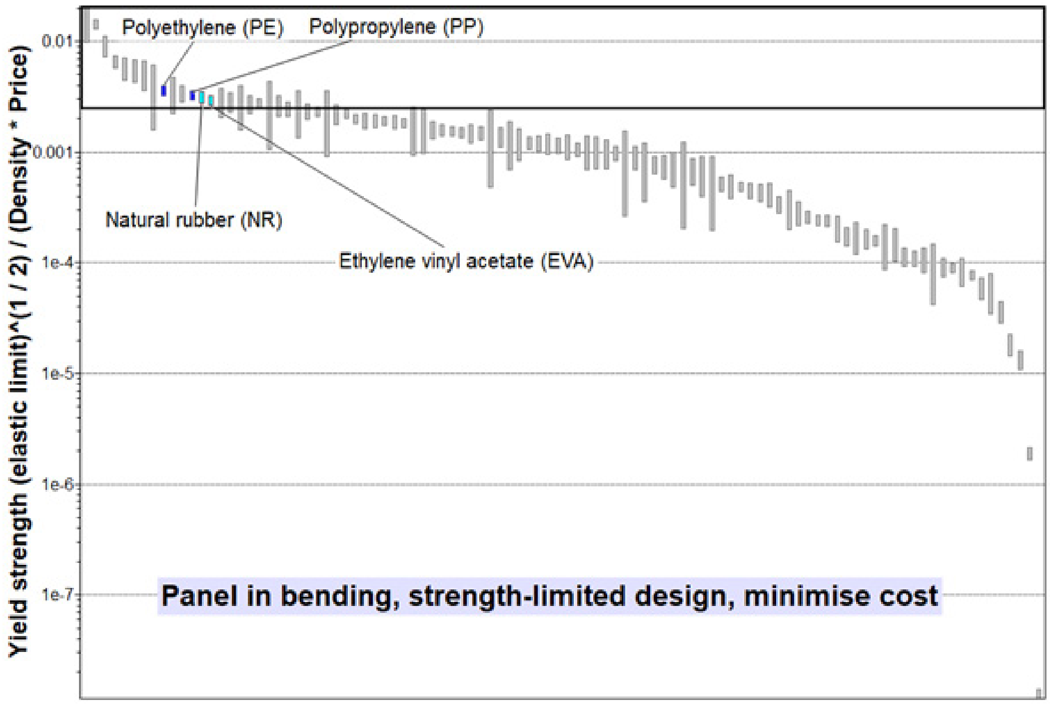

Figure 7: Scuba diving fins translated as panel in bending, strength-limited design, minimize cost.

In both situations, we have used the natural rubber as our reference materials to help us screen materials candidates further. Combining both charts, we are down to four material candidates: polyethylene (PE), polypropylene (PP), natural rubber and ethylene vinyl acetate (EVA).

Let's look into these four candidates in more details:

- Polyethylene (PE) is inert, and extremely resistant to fresh and salt water, at the same time, it is cheap, recyclable and particularly easy to mold and fabricate. It accepts a wide range of colors, can be transparent, translucent or opaque, has a pleasant, slightly waxy feel, can be textured or metal coated as well.
- Polypropylene (PP) is a younger brother of polyethylene (PE), a very similar molecule with similar price, processing methods and application. It is more easily molded than PE, has good transparency and can accept a wider, more vivid range of colors. Fire retardants make it slow to burn and stabilizers give it extreme stability, both to UV radiation and to fresh and salt water and most aqueous solutions. It is inexpensive, light and ductile. Stiffness and strength of it can be improved further by reinforcing with glass, chalk or talc.
- Natural rubber is the most widely used of all elastomers - more than 50% of all produced and an excellent, cheap, general-purpose elastomer with large stretch capacity and useful properties from -50 °C to 115 °C. It has low hysteresis - and is thus very bouncy.
- Ethylene vinyl acetate (EVA) is soft, flexible, tough, resistant to UV and retain these properties down to -60 °C. Fillers improve both hardness and stiffness.

All four materials show potentials to be used in scuba diving fins, we will validate and revisit these materials with some commercial products that are out there in the market in the coming reality check section.

Nowadays, when we come to discuss around new materials for products, especially for sports gears, glass fiber reinforced and carbon fiber reinforced epoxy composites always attract the designer's eyes. Will they fit as material candidates for scuba diving fins as well? We could see that they did not pass the material selection with our above mentioned criteria, but in Figure 8, we could also observe these two materials are still promising due to their excellent specific stiffness and specific strength comparing with other materials in Level 2 database, paring with coating and other processes, they will allow designing of lighter, sleeker and more extreme scuba diving fins as well.

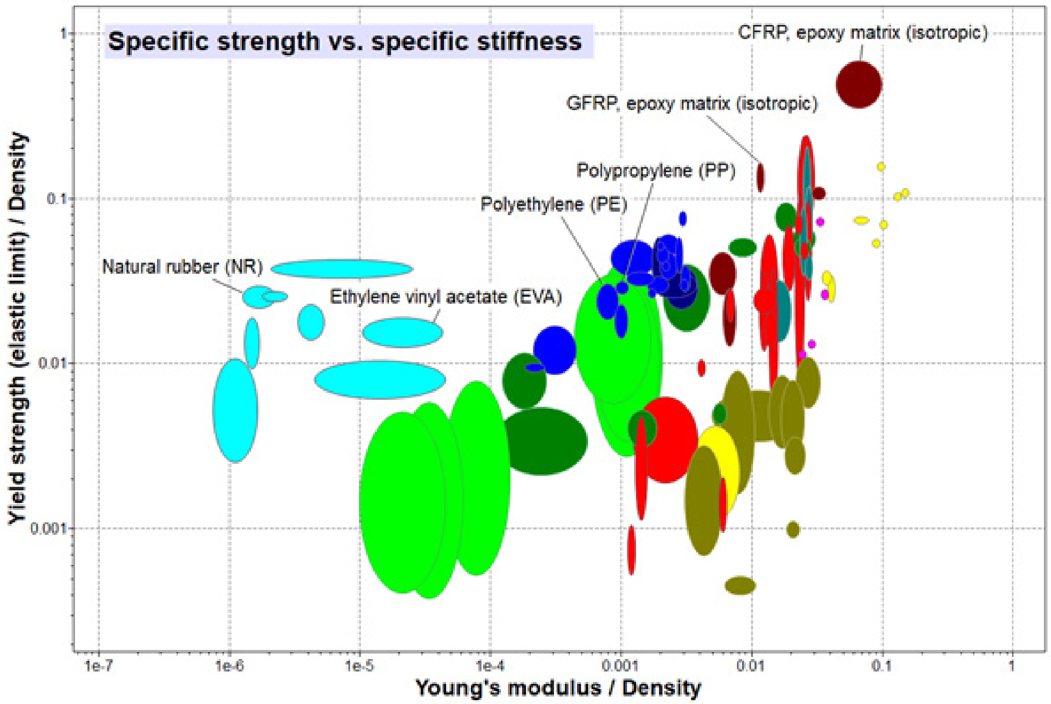

Figure 8: Specific strength vs. specific stiffness for all materials in Level 2 database

4. Reality check

With Level 2 database and tools in Granta EduPack, we have narrowed down to six materials as the top candidates for scuba diving fins: PE, PP (similar as PE), natural rubber and EVA together with glass fiber reinforced and carbon fiber reinforced epoxy composites. In reality, a pair of scuba diving fins can be made with a mixture of these materials: one of the ways is the foot pocket can be molded from soft rubber for maximum comfort while the blade is made from plastics or composites to improve speed and guarantee propulsion and maintain light, while the other popular way is to develop new composites to fulfill different needs with these materials in different structures and combinations. Taking Cressi, Scubapro and Mares, three of the most well-known and popular scuba diving brands as examples, we will be looking at the materials of their most popular scuba diving fins to see how these materials are used in reality.

Cressi is a brand that has been around since 1946 and offers a range of scuba diving fins, one of their most popular models is the 'Frog Plus' fins, which utilizes Cressi's patented three material injection molding process with polypropylene (PP) as the main body [4]. Their 'Clio' snorkeling fins blade, on the other hand, is made of EVA to increase the life and ensures a good responsiveness delivering good power with any kicking style and a favorite snorkel fin for anyone on a budget [5].

Scubapro is famous for their advanced technologies with intuitive, sophisticated designs. 'Seawing Nova' fins as one of their award-winning models, are made from modern Monprene, which is a thermoplastic vulcanizate (TPV) based elastomer, with a composition of blend of polypropylene (PP) (~40%) and vulcanized ethylene propylene diene copolymer/terpolymer (EPDM) rubber (~60%) with EPDM particles encased in a continuous matrix of PP [6].

Mares started out making diving masks and spearguns in 1949 and now it is expanded as one of the largest diving equipment manufacturers around the world. They have several models made from fiber reinforced polymers, either only with carbon fibers or with a mixture of carbon and glass fibers together. One of their signature models, the 'X-STREAM' fins, is made from only carbon fiber reinforced polymer to boost its performance [7].

5. Conclusions

In this case study, we have looked for materials of scuba diving fins that have a good compromise between maneuverability, comfort and size, durability, buoyancy and cost. Using Granta EduPack providing the necessary information and tools for an interactive and visual investigation, we have narrowed down our material candidates to six materials as the top candidates for scuba diving fins: PE, PP (similar as PE), natural rubber and EVA, glass fiber reinforced and carbon fiber reinforced epoxy composites, which are also the materials commonly used in some of the largest diving gear manufacturers, such as Cressi, Scubapro and Mares.

As a next step, we will take these material candidates into Ansys Discovery to further discuss the design of the scuba diving fins to generate enough thrust for divers to move under water in the second part of this case study (case study can be found on the Ansys Education Resources site).

Note

More information on the SCUBA equipment can be found on the official website of Professional Association of Diving Instructors (PADI) [1] [2]. Among all the gears, diving suits are the most materials related, and there are two different types of diving suits, wetsuits and drysuits. Here, we will share some quick fun facts on diving suit materials if you would like to explore more: Wetsuits are skin-tight and for other water sports, such as surfing, as well. They are basically made from neoprene which is a synthetic rubber honeycombed with gas bubbles and also made of fabric, which has a role of reinforcement, to solidify the neoprene foam. So, it keeps you warm by our body heating up the layer of water in-between our body and the wetsuit. Depending on the water temperature, we could have 1mm, 3mm, 5mm, 7mm, 10mm thick wetsuits. The thicker it is, the harder it is for you to move, but wet suit generally allows you to move around more freely comparing with drysuits. Really cold diving spots, like in Iceland and around the South Pole, require drysuits, completely waterproof, that has an air layer for thermal insulation and where you need to wear clothing to keep warm. There are many different drysuit materials (neoprene, crushed neoprene, vulcanized rubber, trilaminate) but nowadays for recreational dry suit diving there are 2 main types – neoprene and membrane/trilaminate. You can also wear drysuit in warm water of course, and you can pump air in drysuit to adjust buoyancy. Drysuits are more expensive and harder to maintain. If you do not go pro diving, most of the cases, for the fun diving spots, wet suits will be more than enough.

6. References

[1] PADI (n.d.), about SCUBA gear from: https://www.padi.com/gear?equipment=All

[2] PADI (n.d.), about SCUBA gear, specifically on fins from: https://www.padi.com/gear/fins

[3] Michael F. Ashby. (2011). Materials Selection in Mechanical Design. https://doi.org/10.1016/C2009-0-25539-5

[4] Cressi (n.d.), about Frog Plus Fins from https://store.cressi.com/products/frog-plus-fins

[5] Cressi (n.d.), about Clio Fins from https://store.cressi.com/products/clio-fins?_pos=1&_sid=dd336c656&_ss=r

[6] Scubapro (n.d.), about Seawing Nova Fins from https://ww2.scubapro.com/en-GB/HKG/essentials/fins/products/seawing-nova.aspx

[7] Mares (n.d.), about X-wing C-EVO Fins from https://www.mares.com/en_GB/x-wing-c-evo-420423

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