# Material Selection for Aerator

**Conceptual Design Identification**

This report explores material selection for the Aerator, designed to prevent burns from hot liquids, and recommends a single material for the construction of the mesh that is most appropriate under the requirements of safety and economy.

**Summary of the Recommended Detailed Design Option**

The mesh should be entirely made from AISI-316L Stainless Steel with #2B finish.

**Context and Motivation**

Material selection of the aerator crucially decides its safety, cleanability, and durability qualities. The aerator will be involved in the preparation of food products, and its material safety must comply with NSF commercial food equipment standards to sell in North America [1] and the European Hygienic Design Group (EHEDG) standards to sell in Europe. [2] In addition, investigation into material selection will set requirements and constraints on the shape and size of the mesh, depending on how easy the material is to machine.

**Requirements**

Requirements on the material are compiled from various international standards and guidelines, [1] [2] [3] [4] and selected using engineering judgement based on what is applicable to an aerator. Cleanability has been reframed down to smoothness and hardness as these two properties determine the difficulty of keeping the material clean while being quantifiable. Chlorine will be the most common oxidizing agent as it is involved in the sanitation of water.

| Objective and Justification | Metric | Constraint | Criteria |
|---|---|---|---|
| **Corrosion resistivity** – need to avoid contaminating the liquid poured through it | Milimeter per year in 100% acetic acid at boiling – 118$^0$C (mm/y) [5] [6] | <0.05 (Appendix B) | Less is better |
| **Smoothness** – need to avoid crevices which provide room for bacterial growth | Roughness average in ($8\mu m$) | <$0.8\mu m$ [2] [7] | Less is better |
| **Hardness** – need to allow for cleaning without damaging the surface and compromising its smoothness | Vicker's pyramid number (HV) [8] | Should be >120 (Appendix C) | More is better |

Table 1. Objectives, metrics, constraints, and criteria of various requirements. Acetic acid was used to measure corrosion resistivity as it is one of the most common acids found in foods. [9]

The material must also be nontoxic as in the corrosion process does not release harmful levels of the material into the water, which is specific for each material. The material must also be non-absorbent, meaning liquid particles cannot be trapped in the structure of the material.

**Alternatives Considered**

Three alternatives were considered – grade 2 titanium with mill finish, 5052 grade aluminum with mill finish, and food grade silicone with shore D hardness.

**Detailed Justification of Recommendation against Alternatives**

| Candidate | Corrosion resistivity (mm/y) | Smoothness ($\mu m$) (more in Appendix F) | Hardness (HV) |
|---|---|---|---|
| AISI 316L Stainless Steel with #2B finish | 0.01 [5] [9] | 0.127 – 0.635 [10] | 155-180 [8] |
| Grade 2 Titanium with mill finish (unpolished) | 0 [5] | 0.2 – 0.5 | 145 [8] |
| 5052 Aluminum with mill finish (unpolished) | 0.011 [11] | 0.642 [12] | 68 [8] |
| Food grade silicone (Shore D hardness) | Variable | Variable | <30 |

Table 2. Comparison of alternatives and recommended choice on requirements. Food grade silicone is an emerging material in the food industry and have no specific grades to assign values to.

Based on quantitative data alone, 316L steel and grade 2 titanium clearly wins in terms of hardness. Both of these can be cleaned with steel wool, which has a hardness of around 100HV, while aluminum and food grade silicone cannot.

However, additional factors such as availability, weight, and cost need to be considered.

Titanium is rarely used in the food and pharmaceutical industry mainly because of its lack of advantage over stainless steel and comparatively expensive cost. Titanium's increased corrosion resistance are only applicable under heavy corrosive stress, which the aerator is unlikely to encounter. (Appendix D)

5052 aluminum has particular good resistance against salt water corrosion and is used to make heavy duty cooking utensils. [13] It is is highly resistant to corrosion by acids, but contact with alkali compromises its protective oxide skin. It is more economical than stainless steel, being very light weight, but has low surface hardness and scratches more easily, compromising smoothness. [14] Additionally, it is not suited for use in Ontario and other places with high alkaline concentrations in tap water. The leaching of aluminum is under investigation for causation of Alzheimer's, making aluminum a potential health concern. [15]

Food grade silicone have little assurance of durability and maintenance of cleanability; they are subject to cracking and clouding from prolonged exposure to corrosive food and cleaning agents. [16] They are softer than the metallic alternatives and thus cannot be cleaned with steel wool. There is no one standard for food grade silicone, damaging the predictability of its properties. An advantage they have over the metals is that they are lighter and cheaper than steel.

Stainless steel is made from iron, chromium, and nickel. Materials inevitable leach; however stainless steel cookware provides less than 20% of Canadian's total daily iron intake. [16] Nickel is poisonous even in small quantities, and the average adult safely consumes 150-250mg of Nickel per day, but stainless steel cookware does not add significant amounts of nickel to diets. [16] Chromium intake is safe between 50-200mg/day and one meal prepared with stainless steel adds 45mg of chromium, which is within safe bounds. [16] [17]

Stainless steel's greatest advantage is its strong documentation. The prevalence of it is backed by extensive existing literature on its safety, providing a reliability advantage compared to the less common alternatives.

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## Appendix A

The European Union's legislation proposes requirements on food safety, but does not have specific metrics and criteria on complying with these requirements. The EHEDG is a non-government organization that provides guidelines including practical metrics and criteria to meet those requirements.

Stainless steel 200, 300, and 400 series are all considered "food" metal, however there are some differences that distinguish 316L as the most appropriate grade. The 200 series have similar mechanical property to the 300 series, but are more susceptible to corrosion at temperatures higher than $50^0$C. The 400 series have poor resistance to corrosion but have superior mechanical properties; however, the role of an aerator would place it more often in corrosive stress rather than mechanical stress. Inside the 300 series, there are the 304, 304L, 316, and 316L grade. 316 grades resist corrosion better at higher temperatures (>$50^0$C) , but are slightly more expensive than 304 grades. 316L denotes the grade has power carbon content, in effect reducing the stiffness of the material. The reduced stiffness enables the material to be machined more easily, reducing the risk of welding and bending induced cracks, which contributes to corrosion. [18] The compromise of stiffness for smoothness is advantageous because the aerator will not be placed under heavy mechanical stress.

**Appendix B**

The current mesh design is 0.15mm thick, and a degradation of over 5% is considered failure. [9] The intended life cycle of a static consumer product is usually 15 years, [19] so that permits 0.0005mm/y of corrosion. However, the product will not be submerged in 100% acetic acid for the course of that time; assume the average corrosive stress will be 1% of that, so allow 0.05mm/y under 100% acetic acid at boiling temperature.

**Appendix C**

The mesh must be harder than any physical tool used to clean it in order to avoid scratches. Steel wool is rated at 60-100HV, [8] and assuming steel wool is the hardest material a user would use to clean their mesh, the minimum hardness of the material should be 120HV, given a 1.2 factor of safety. The product can be under 120HV if steel wool is not used to clean it.

**Appendix D**

| Type | Uses | Hazards | Examples |
|---|---|---|---|
| Strong Alkali | Destroys microbes and dissolves protein | Corrosive | Sodium hydroxide (ingredient in oven and bakeware cleaners) |
| Heavy-duty Alkali | Removes fats | Corrosive | Sodium carbonate (descaling agent for coffee pots and espresso machines) [20] |
| Mild Alkali | Food additives, soaps, solvents | - | Sodium bicarbonate (baking soda) |
| Mild Acid | Food additives, food | - | Citric acid (tea, juice) |
| Chlorides | Kitchen cleaners, sanitization | Strong oxidizer | Bleach, tap water |

Table 3. Common corrosion inducing substances the aerator is likely to encounter. [21]

**Appendix E**

Only grade 1 and 2 titanium are used in food processing and pharmaceuticals.

Silicone rubber has 3 hardness grades – shore A00, ones that are very soft, shore A, flexible mold rubbers, and shore D, rigid.

**Appendix F**

| Surface treatment | Range of roughness average (μm) | Typical features of the technique |
|---|---|---|
| Hot rolling | > 4 | Unbroken surface |
| Cold rolling | 0.2 - 0.5 | Smooth unbroken surface |
| Glass bead blasting | < 1.2 | Surface rupturing |
| Ceramic blasting | < 1.2 | Surface rupturing |
| Micropeening | < 1 | Deformed (peened) surface irregularities |
| Descaling | 0.6 – 1.3 | Crevices depending on initial surface |
| Pickling | 0.5 – 1.0 | High peaks, deep valleys |
| Electropolishing | | Rounds off peaks without necessarily improving Ra |
| Mechanical polishing with aluminium oxide or silicon carbide<br><br>Abrasive grit number<br>500<br>320<br>240<br>180<br>120<br>60 | <br><br><br><br><br>0.1 – 0.25<br>0.15 – 0.4<br>0.2 – 0.5<br>= 0.6<br>= 1.1<br>= 3.5 | Surface topography highly dependent on process parameters, such as belt speed and pressure. |

Table 4. Surface treatments of stainless steel and resulting surface topography. [2]

| Finish Number | Method | Range of roughness average ($\mu m$) | Qualitative information |
|---|---|---|---|
| #2B | Unpolished | 0.127 – 0.635 | Standard mill gauge finish with a bright finish; common |
| #2BE | Electropolished | 0.076 – 0.381 | Bright cold rolled finish with an electropolish after fabrication |
| #2BA | Unpolished | 0.076 – 0.254 | Bright cold rolled finish with final annealing |
| #2BAE | Electropolished | < 0.127 | Bright cold rolled 2BA finish with final electropolish |
| #4E | Electropolished | < 0.76 | General purpose and mechanically ground; interior finish for food and pharmaceuticals; common |

Table 5. Surface finishing of stainless steel and resulting surface topography. [17] [22]