Surface Treatment of Aluminium

As a sustainable and versatile approach to integrate aluminium and optimise consumer products

Pia Sofie Sollund
Department of Design
NTNU, Norwegian University of Science and Technology

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ABSTRACT

Aluminium is a highly versatile material, however the cold and industrial aesthetics of the materials' surface limits its application. A material's surface is one of the main contributors to a product's aesthetics. It is therefore essential that the designer is aware of its attributes and can design the surface to achieve the desired sensorial properties and emotional characteristics. Aluminium's surface has characteristics that are often unsuitable for direct user interaction. Treating the material's surface can however change its characteristics and broaden its area of application. Thus, getting to know these finishing techniques and their application becomes an important component in the process of integrating more aluminium in consumer products.

Findings from a literary review are used to discuss aluminium's potential as a material in consumer goods, with a focus on sustainability and design properties. This is also used to discuss several aspects of product surfaces, and the affect it has on the user's perception of the product. The article also explores different finishing techniques for aluminium with a focus on application, method and sustainability. The findings are then used to establish how suitable aluminium is as a material as well as how surface treatments can affect its application. The results from the article are meant to help familiarize the designer with available surface treatments of aluminium, and the potential it has as a material in consumer products. Additionally, it's intended to raise awareness of the importance of surface treatment in product design, and how to utilise surface design in optimisation of products.

KEYWORDS: Product Surface, Surface Design, Aluminium, Surface semantics, Sustainability

1. INTRODUCTION

An optimized consumer product consists of many essential factors that together creates a successful object. One crucial component is the product's surface, this contributes to several of its attributes such as texture, appearance and functionality. The chosen surface can come from the selected material in its natural state, or it can be obtained by using different surface treatments and finishing techniques. These consists of applying a process to a material to increase its qualities, both physical and aesthetical.

A variety of different surface treatments can be applied to the metal aluminium [1]. The metal has several positive attributes, however the most common applications of the metal are generally in areas that are not in direct contact with the user. They are not largely found in consumer products, items that are commonly used, and in direct contact with the user who ordinarily buys it for private consumption [2]. Consumer products, or consumer goods are the everyday objects we interact with and which constantly surrounds us. Aluminium is albeit applied in some consumer products, however there is still a considerable potential for increasing this area of application.

One of the main reasons why aluminium is not widely used in consumer products is the way the material is perceived by the users. The

characteristics of the metal is often viewed as cold, hard, and industrial with its non-nonsense appearance [3]. In other words, it gives of an expression that can be perceived as practical, sensible and straight forward, and won't necessarily correlate with other potentially desired characteristics such as playfulness, warmth or luxury. Consequently, these aesthetic and emotional properties limit the use of the material in products with high user interaction.

This article first studies how suitable aluminium is as a material by examining the metal's properties, field of application and environmental footprint. Next, the focus shifts to product surfaces. This includes investigating sensorial properties of the surfaces as well as surface semantics. Finally, a mapping of available surface treatments of aluminium is conducted, exploring sustainability, versatility and fields of application. These factors are ultimately compared in the final section and evaluated together with a case study.

The intention of the article is to present a range of available surface treatments of aluminium, while also exploring the importance of surfaces in product design. This is then used to discuss the potential of surface treatment of aluminium as a instrument to integrate more aluminium into consumer goods and optimize these products in a sustainable fashion.

2. LITERARY REVIEW

The results from this article derive from a literary review which was used to gather information, insight and understand regarding three main topics, these include:

1) Surfaces' role in product design and its sensorial and emotional properties.
2) Aluminium as a material its sustainable properties
3) Surface treatments of aluminium.

The literary review was based on a selection of sources. These mainly included books and articles from NTNU's academic database and Google scholar, they were considered as trusted sources with reliable information. The results are also supplemented through web searches. This to study how surface treatment of aluminium is being utilised in industrial design and find contemporary techniques and updated sustainable statistics. I've used advanced search engines to get accurate results, and used keywords such as product semantics, sensorial perceptions, product surfaces, industrial design and a combination of aluminium and aluminium.

This article has also been related to a corresponding project where the objective is to incorporate more aluminium in product design and communicate the potential of aluminium as a material to industrial designers. Collaborators of this project are Hydro and Hareide design, hence some information is a result from working on this project.

The results from this literary review should be objective, hence I tried to find multiple sources on the same topic. Some of the sources may however be biased, as a lot of the information comes from manufacturers of aluminium such as Hydro. They promote the material, and it's important to remember that they have particular interests in distributing more of the metal.

3. ALUMINIUM

This article focuses on introducing more aluminium into consumer products, consequently we need to be certain that aluminium is indeed a suitable material. Designers have to be aware of the different aspects of their materials, from manufacturability to aesthetics. They also have an ethical responsibility when it comes to sustainable material selection. Thus, the intention of this chapter is to explore aluminium as a material. The chapter starts off with section 3.1, which studies the properties of aluminium, followed by the applications of aluminium as a material in section 3.2. Finally, section 3.3 investigates how sustainable aluminium really is.

3.1 Properties of aluminium

Aluminium is one of the lightest metals on earth, making it both functional as well as sustainable to transport [4]. It is also extremely ductile and flexible, which is exemplified by the aluminium foil, as it can be rolled to a thickness of 0.2mm. This ductility creates a vast design flexibility and contributes to making the metal extremely formable [4].

Strength is also a selling point, however it is not the strongest metal and can be deformed. One method of reducing this risk however, is to use aluminium

alloys. Aluminium's ability to easily bind with other elements is utilised to create the alloys. By adding small amounts of other elements such as magnesium and silicon, the metal's characteristics can be drastically changed which helps increase the field of application for aluminium.

A relevant feature of aluminium's surface is its ability to be physically modified by the use of surface treatments [1]. It's one of the most versatile materials in this regard. The natural state of Aluminium's surface also provides desired features. A thin layer of oxide creates a protective barrier and makes the metal corrosion resistant [6]. Thus, creating a low maintenance material. Additionally, the metal is reflective, a super conductor, completely impermeable, which means it is perfect for food packaging, as well as fireproof.

3.2 Applications of aluminium

The most common applications of the metal are currently in areas that are not in direct contact with the user [1]. There are three main areas of application. It is used in transportation due to the metal's light weight, strength and ductility. Additionally, aluminium's ability as a super conductor makes it one of the most common materials in electrical components. Finally, the strength of the aluminium alloys and its corrosion resistant layer makes the material suitable for construction. The corrosion resistance also makes aluminium common in products that are in harsh environments with low accessibility such as space or outdoors, areas that need a low maintenance and a sturdy material [5].

Aluminium is also applied in some consumer products, such as soda cans, pots and pans, some furniture design, as well as most of the famous Apple products. However, this is still an area of application that can be significantly expanded.

3.3 Aluminium and sustainability

Aluminium is promoted as an environmentally friendly material by its manufacturers, who tend to call it "The green metal" [7], [8]. However, these parties may be biased, hence it's important to investigate this claim further.

Aluminium is the most abundant element in the earth's crust after oxygen and silicon, which makes it the most widespread metal on earth. However, pure aluminium does not occur in nature, which means it must be processed from other materials, and this manufacturing process is not unproblematic. The most common mineral used for aluminium production is bauxite, a red clay that mainly appears in subtropical areas [9]. The bauxite mines can be located in vulnerable areas and the mining can cause big destruction to local ecosystems. The bauxite is processed into alumina, which later is processed into aluminium using electrolytic reduction. This process requires enormous amounts of energy. In addition to the high energy consumption, the smelting process requires large amounts of water. Finally, the process of reducing alumina emits greenhouse gasses [10]. This last element might however see changes in the future. The metal companies Alcoa and Rio Tinto, in collaboration with Apple, have developed a new technique of the smelting which only emits oxygen [11], [12].

Recyclability also becomes an important topic in the discussion of aluminium and sustainability. Aluminium can be melted down and reused infinitely, and the re-melting only requires 5% of the energy that is initially needed to produce new aluminium [6]. About 75% of the aluminium that has ever been produced is in fact still in use today. This is one of the material's main environmentally friendly advantages and can be of use when creating consumer products.

This can also contribute to fight the challenge of increased plastic consumption the society faces today. Around 299 million tons of plastic was produced in 2013, and this global plastic consumption has been increasing for the last 50 years by replacing materials such as glass and metal [13]. The efforts of recycling this material has unfortunately been quite insufficient and millions of tons of plastic ends up in landfills and the oceans every year. A part of the solution to this problem could be to reverse the latest material development and go back to more traditional materials which can be reused in a more efficient way.

4. SURFACES IN CONSUMER PRODUCTS

A product's surface refers to the outermost or topmost part of the product and is generally designed in the later phases of the design process [14]. A study conducted by Zuo et al. in 2016

explored the sensory perception of material texture in consumer products. Evaluation tests from this study showed that the main attributes which contributed to the aesthetics of a product were shape, colour, materials and surface finish, in other words, the surface plays a vital role in the design and appearance of a product [15]. This chapter examines the role of the product's surface and its significance. Starting with section 4.1 which looks closer into the sensorial properties of the surface, followed by 4.2 that studies the meaning surfaces express. Section 4.3 gathers several general observations of user interaction with surfaces and their reactions. Finally, 4.4 describes important factors that are of essential when designing the surface.

4.1 Sensory perception of the surface

When a consumer comes in direct contact with a product, they start a process using their senses including sight, touch, smell, taste and/or hearing, to assess it [15]. The properties that are used to describe this interaction between the user and the material is called sensorial properties. These can include tactile aspects such as rough or warm, or visual aspects like blue and shiny [16].

Most of these sensorial properties are tightly bound to the surface of the product. Attributes such as texture, temperature, reflectance and colour are all factors that combined makes up the product surface and are experienced through the user's senses. The process of creating sensorial experiences is agreed to play an essential role in the aesthetic experience of the design, and it can also change the overall impression of the product [17].

Human tactile sensibility gains more attention in product design, and it's agreed that it's closely related to the purchase decision of the user, which is supported by the fact that approximately 70% of consumer buying decisions in the small domestic appliances market are made at the point of sale [15]. Hence, it's essential to appropriately incorporate the human senses in surface design to meet the user requirements and optimise the product [14].

4.2 Surface semantics

When optimising the product design, it's important to not only make an aesthetically pleasing product based on the sensorial properties, but also keep in mind the emotional aspects [14], [16]. These help the user perceive value and quality in the product, in other words, the product needs to meet the emotional expectations through channels beyond the senses [15]. This include product semantics, the meanings of the product and the emotions in design [18]. They are abstract and expressive characteristics that are attributed to the product. This can be characteristics such as welcoming, childish, professional, sensual, masculine, feminine, playful or strict, features that the users attribute to the design through sensory exploration and associations.

The product surface evokes a lot of emotions during user interaction, thus creating surface semantics, expressive meanings and associations regarding the surface. These characteristics are not a factual or physical part of the materials, the materials aren't for instance literally masculine or feminine, however they are abstract traits that the users experience from interacting with the product[16]. The expressive associations are usually an essential part of a user's material description, a fact supporting the importance of emotion in optimising design.

There is generally a growing interest in the more intangible side of product design, and both designers and manufacturers are becoming aware of the influential role the user's emotions have in appraising the product. To optimise the user interaction, the designers have to create surfaces that generates the correct meanings and message to the user [16].

4.3 Sensorial and semantic responses to surfaces

There has been conducted several studies on the relationship between users and product surfaces. Many of these explore general perception of textures and finishes, which surfaces creates the most positive responses. Two of these studies, [19], [20] concluded that people prefer to touch smooth surfaces over rough ones, as they are warm and generate desirable feelings. The study by Zao et al. on the other hand discovered that surface shininess was a trait that mainly generated positive feelings.

As the users generally responded lively and cheerful to shiny surfaces [15].

Other studies have shown that there are several sensory responses to surfaces, which creates correlations between the different characteristics of the materials. In other words, there is a relationship between the associations, for example a smooth surface is also associated with feelings of coldness, shininess and moistness. Other related associations are; roughness/dryness, flatness/stickiness, and warmth/softness [21].

Zao et al. also investigated how users give meanings to materials. They created five categories with meanings that were all conceptually different. The expressional characteristics were; 1) aggressive, 2) nostalgic, 3) professional, 4) sexy and 5) toy-like. The participants were then directed to choose five products, one for each category of meaning based on emotional associations the materials expressed. The results included the not surprising observation of people associating certain materials to certain meanings, supporting the theories of surface semantics. Further, it discovered that metal was one of only two materials that was associated with all the five characteristics [15]. Metal as a material is also perceived to have a higher value and quality than plastic by most users [22].

4.4 Surface Design

To design a consumer product's surface, the designer needs to consider both material selection and potential surface treatments to achieve the right sensorial and expressional characteristics. It is agreed by scholars that materials have a significant role in creating product values and meaning, and it's therefore essential for the designer to get the right insight in material selection [23]. There are four main dimensions to material selection, these include; manufacturing properties, functional properties, sensory and aesthetic characteristics and finally ecological characteristics [15]. The sensory and aesthetic characteristics are clearly part of the user-interaction aspects of the material, which influence how the user perceives the material. A high-quality product should be made out of materials that fulfil requirements for all the dimensions [24].

The selected materials give meaning to the products by the help of the previously mentioned expressional characteristics. They have a significant role in influencing the user's perception of the product's aesthetics. However, these characteristics may be changed.

This relationship between the materials characteristics and the emotional alterations are explained by Zuo et al. in their 2016 study by the use of a metaphor. They compare the product's material to an actor, and the surface as the character the actor is portraying. People can appreciate a movie for many different reasons, including the storyline, soundtrack or the performance by the actors. Products are appreciated by the users in the same way, they are influenced by different factors such as sounds, function, texture, colour etc. In the same way as an actor has their own characteristics such as appearance and temperament, materials have their own attributes. Aluminium tends to feel cold, hard and smooth while wood feels warm, organic and fragrant. However, when an actor plays a role, he or she can change their character and portray someone completely different. This also applies to materials.

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The example used in the study is of a museum door made out of metal. The original characteristics of the metal is cold, industrial and hard. However, by treating the surface, the door's characteristics can be completely changed. Applying a rusty finish can signify a sense of time and history. This alters the perception of the door and enhances the user experience by adding meaning to the product's surface through emotional associations of stability, traditions and endurance [15].

There are different factors that can help change these characteristics of a material. One is the combination of other materials. Effective use of different materials can create a dynamic impression as well as altering the product's expression. It is also shown that context is important when it comes to expressional characteristics. Different products can have the same material, however the context affect how they are perceived [21]. An aluminium profile used in construction has a completely different expression than an aluminium profile used as a part of a bookshelf in a home. Applying certain processes to the materials can also alter the characteristics [16]. Different manufacturing processes creates different sensorial experiences.

These can change the overall impression of the products. For instance, bending one big aluminium plate into the correct shape can generate more meaning of flow and an organic appearance compared to welding smaller steel plates together.

The main approach to alteration of the characteristics is however surface treatment. Finishing techniques, next to material selection, is the most essential part of surface design, as it modifies the sensorial experiences and the emotional meaning of the materials.

5. SURFACE TREATMENT OF ALUMINIUM

Untreated aluminium has a beautiful light, silver colour and a natural protective oxide layer on its surface. However, there are still many reasons to treat the surface of the material [5]. There are two main reasons for treating aluminium, firstly, to improve the function of the material. Functional treatments can include improving the surface's corrosion resistance, add hardness or aid in resisting wear and tear. The second motivation for treating the surface is for aesthetic purposes [1]. The surface treatments can create reflective properties, add colour or change the material's texture and so on [25]. This chapter focuses on some of the most common decorative finishing techniques for aluminium. The following eight sections each studies a new technique and describes its method and application.

5.1 Mechanical finishes

There are several mechanical techniques that can be applied to aluminium's surface [1]. The products can also be exposed to other treatments after the mechanical finishes are applied.

Abrasive blasting, also known as sandblasting is a common mechanical finishing technique that is both versatile and effective [26]. Particles are fed through a gun, and at high velocity these particles blast the material. This can either create smooth or rough surfaces, in addition to patterns by the use of stencils.

Figure 1. Sandblasted sculpture with laser engraved details.

Polishing can also drastically change the surface of aluminium. By running a soft cloth with abrasive grains over the surface, the material is given a smooth and shiny appearance. Buffing is similar to polishing and helps smoothen the surface, however this uses less grains than polishing.

Mass finishing are finishing techniques that allow a large amount of parts to be treated simultaneously. Tumble finishing, or rumbling, is the most common of these [5]. The process involves placing the aluminium parts in a rotating barrel filled with abrasive. This can create either a smooth or rough surface, depending on the size and type of abrasive.

5.2 Laser Engraving

Laser engraving is a great tool for adding details to aluminium's surface [27]. A computer controls the laser and it can be used to cut both curved and flat surfaces. This technique helps raise the appearance of the product to a new level by adding important details. Is it often used in jewellery design, for logos and general lettering as well as patterns.

5.3 Acid etching

Acid etching, also known as chemical milling is a process to decorate metallic products [27]. The process of acid etching involves placing a layer on top of the object to protect the areas that will remain unchanged. The object is then exposed to acid which eats away the areas that are not covered by the protecting layer. This technique can create intricate patterns on various aluminium objects.

Figure 2. Intricate use of acid etching for decoration purposes in knife design.

5.4 Bright Dipping

Bright dipping is an option when the designer is looking for an extremely polished and shiny surface for their aluminium part [5]. By bathing the aluminium components in a solution of phosphoric and nitric acid, the surface is smoothened out on a microscopic level. This created a mirror finish to the surface. There are some downsides to this technique however, as the solution used for the dipping is toxic and can create greenhouse gases. [28], [29]. Electrochemical brightening processes are however widely used industrial design, the most common application of this finish is jewelleries, domestic appliances and car components.

Figure 3. These bright dipped components display the reflective properties created by the technique.

5.5 Suede coating

Aluminium is often perceived as a cold and hard material, however a fun way to change this is by applying a technique called suede coating [27]. This is a process developed at the request of NASA who needed a material for the interior surfaces of their space shuttles however now it's used in all kinds of products. It creates a soft, velvety surface by applying a layer of primer and a layer of coloured granules. By using this technique, a designer can obtain a hard-wearing and soft-feeling surface. This technique is also considered sustainable without any hazardous emissions.

Figure 4. Application of suede coating creates a soft surface texture.

5.6 Powder coating

Powder coating is a highly common technique for surface treatments of many different materials, including aluminium. The process of powder coating involves spraying a dry mixture of resin and pigment through an electrostatic gun [30]. This coating is tougher than conventional paint, as well as it is easy to repair potential damages. An aluminium product that has been powder coated will lose some of the "aluminium look", however the texture can become anywhere between super matt and super glossy, in an array of different colours, the only thing that dictates the finish is the designer [27].

An additional interesting application of powder coating is in combination with sublimation [31]. Sublimation is applying a picture on the aluminium using a film with a pattern, followed by air removal and curing. Combining this with powder coating can create different effects such as the appearance of wood, see figure 5.

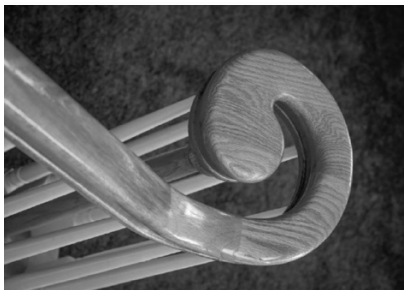

Figure 5. Powder coating and sublimation creates a "wood-effect".

The process of powder coating does not emit any air pollution, and the excess powder can be reused, this makes powder coating a sustainable option for surface treatments [**5**]. Common application of

powder coating in product design is on bikes, automobile parts and lately furniture.

Figure 6. IKEA Candle holder of powder coated aluminium. Design by HAY

5.7 Liquid paint

Another common finish for aluminium is liquid paint. The technique consists of applying liquid paint using a spray gun. The benefits of this technique are primarily the range of colours available, virtually any colour can be applied and it's easy for the colours to be bespoke. Secondly, liquid painting is convenient and price effective for finishing a small batch of products. However, this process does involve emitting volatile organic compounds (VOCs) into the air, making it less sustainable than powder coating. The results can also be varied as the appearance of the colour and finish are based on a day-to-day combination of equipment, condition and process [32].

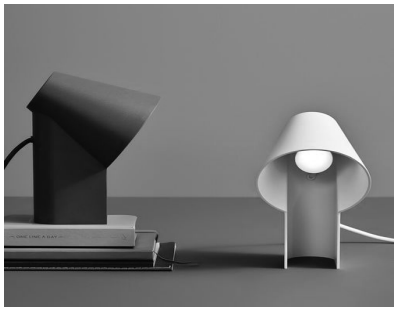

Figure 7. Liquid painted aluminium lamps.

5.8 Anodising

The final, and perhaps most influential finishing technique for aluminium, is anodising. This surface treatment is special as it can only be applied to three materials, where aluminium is the most common one [**5**]. The electrochemical process of anodising aluminium involves immersing the object in an acid solution, followed by applying a current to a cathode already submerged in the bath and the aluminium component which becomes the anode. This process thickens the already existing layer of oxide on the surface of the aluminium. This becomes part of the metal and consequently the finish can't peel, flake or fade, as well as it contributes to a more wear and corrosive resistant material [33]. There are several anodising processes where the variables are the acids, temperatures, voltage and treatment time.

There are also multiple aesthetic benefits of anodising. Colouring the metal can be done right after the anodising process, by immersing the part in a dye bath. The appearance of coloured, anodised aluminium depends on the type of dye applied, and the amount of time the part is submerged in the solution [34]. However, the general appearance is characteristic to anodised aluminium where the metal qualities are conserved. Famous applications of anodising in industrial design are the modern apple products. Both the macbooks, ipods and iphones have a body of anodised aluminium in a range of colours.

Figure 8. The anodized Apple's Iphone 7.

6. DISCUSSION

This article has its main focus on the application of aluminium in consumer products by the help of surface treatments. However, we did uncover a demand for an objective study of aluminium's sustainability to avoid biased sources and false promotion of aluminium. To approach this topic, it's necessary to discuss different aspects of the material. We can see that aluminium has a range of sustainable features, including the amount of available materials which reduces the risk of exhausting the resource. The metal's ability to be recycled is perhaps it's biggest advantage. This combined with its formability can also replace plastic in some areas and help reduce the global plastic consumption.

The more negative aspects of aluminium's sustainability can be traced back to the manufacturing processes of the metal. This includes the potential threat the bauxite mining poses to local ecosystems, greenhouse gasses emitted through the smelting process, and the enormous requirement of energy. It can be argued that these three factors make aluminium an unsustainable material. Nonetheless, there are still arguments that support the manufacturer's claims that aluminium is "the green metal". One aspect is the scientific progress that is currently underway, where results show that they can create aluminium with limited emissions. Secondly, if the manufacturing of aluminium is properly monitored and located, then the ecological footprint will be majorly reduced. This includes locating the factories close to renewable power sources that generate enough sustainable energy to produce the metal, as well as monitoring the bauxite mines and protect the local environments.

Regarding the sustainability of the surface treatments, almost all of them are viewed as sustainable, and the application of the finishing process does not interfere in the recycling process. The exception however, is bright dipping which includes so strong chemicals that it becomes environmentally hazardous. Other substitutes for this technique could be selected forms of polishing.

Aluminium's status as a sustainable product depends on the designers' ability and proactiveness in their design process. The products being produced has to be attuned for recyclability and it demands that the designer considers the entire lifetime of the product.

There are some limitations to the research of the article regarding sustainability. Aluminium has not been largely compared to other materials, more insight in optional material's environmental properties are required to make a complete conclusion of the metal's sustainability. Additionally, several of the sources regarding aluminium's positive traits are from parties that can be biased in their promotion of aluminium. It's important to keep this in mind when considering these arguments.

The research of product surfaces shows the important role it has in product design. Yet, the surface is clearly not the only expressive feature of the product, there are other qualities such as shape, ergonomics, function, communication, sound etc, which contributes to the perception of the product. However, it is shown that the surface contributes to most of the product's aesthetic features. Consequently, it becomes essential to focus on surface design while optimizing products and designing for consumer products. Through sensorial assessment of the surface, the user creates emotional associations and assigns the product meaning and expressive characteristics. These become essential to the relationship the user have with the product and their perception of its quality and value. These characteristics are based on several factors, including texture, temperature, smell, taste, sound, context, colours, reflectance and use of materials.

Hence, changing the surface becomes an instrument to control these expressional characteristics. Thus, the designer can change the user's perception of the product by applying surface design to their design process. This approach adds design flexibility and gives the designer more control. Finishing treatments are clearly the most prudent instrument to control the surfaces as the objective of their use is to modify the surface through application of mechanical or chemical processes.

Ergo, it becomes relevant that one of aluminium's prominent features is its ability for versatile application of surface treatments. The research from observing users' reaction to surfaces also concluded that people generally react positively to smooth and shiny surfaces, features that aluminium naturally has. It also showed that metal was one of the most versatile materials regarding surface semantics, and that it could express a wide range of characteristics from toy-like to professional. This combined with the other features such as strength, light weight, formability and ductility outweighs its negative attributes, and makes aluminium a suitable material for product design.

There are however some limitations to the material regarding consumer products, the natural characteristics of its surface tends to be perceived as cold, hard and industrial. These associations are often not desired in products that are in direct contact with the user. The solution to this problem

becomes surface treatments. The range of available techniques can be applied to modify the sensorial and aesthetic properties of the metal, including various colours, textures, patterns and different levels of reflections. They can create a level of detail that raises the perception of quality in the product. The designer can also apply a combination of different techniques to obtain the desired characteristics. The range of available finishing techniques and their applications makes them a versatile instrument in surface design. This may help in opening the field of application for aluminium regarding consumer products. By making the surface more adaptable, the emotional characteristics become increasingly user friendly.

However, it must be mentioned that surface treatments do have their limitations. There are only so much the techniques can do to modify the materials. Every material has its restrictions, and there are certainly contexts where aluminium is not a suitable material, no matter how versatile the finishing techniques are.

There are several examples showing successful application of surface treated aluminium in consumer products. One company that is a big fan of aluminium for its strength, flexibility and appearance is Bang & Olufsen [35]. They are a Danish design company which specializes in luxury audio and TV equipment. They produce a range of successful products on a global level, and aluminium is the prominent material, as they themselves put it: "*Aluminium has had a crucial and defining effect on what we do here at Bang & Olufsen, not just on how our products perform, but also on how they are designed. Aluminium is at the core of what makes us unique ".* They have incorporated aluminium since 1955 and call their approach to surface design, "*a touch of aluminium alchemy".* Surface treatments applied to their successful BeoPlay H8 headphones firstly consist of mechanical polishing. This creates a spiral like structure that adds detail and reflections to the headphones, see figure 9. Ensuing this is the anodizing and colouring of the aluminium component.

Figure 9. H8 Beoplay headset. Polished structures and anodized aluminium.

The colours at Bang & Olufsen are carefully designed, and the anodization process allows for the desired appearance. This use of aluminium and finishing techniques, combined with other materials and context, creates a high-quality product which is undeniably suitable as a consumer product. This supports the theory that surface treatments can help integrate aluminium in consumer products.

Finally, there are some limitations to the research of surface treatments. There is a wide range of available techniques, and this article only skims the surface. A broader exploration of finishes may display increased versatility and applications.

7. CONCLUSION

Throughout this article it becomes apparent that the surfaces of products are essential to a user's perception of the object. The users react to the sensorial properties of the surface and assign meaning to the product. This emotional connection creates a perceived value and influences the person's impression of the product and affect their purchasing-decision as a consumer. Thus, surface design becomes an important instrument in optimizing consumer products.

We can also conclude that with the right monitoring and precautions, aluminium and most of its surface treatments can be considered sustainable. However, it does require that the designer considers recyclability and product lifetime in their design process. Additional observations show that aluminium is a suitable material for consumer products, as long as it's used in the right context and with appropriate surface treatments applied. These surface treatments consist of a range of mechanical and chemical processes that can change the aesthetics of a surface, including colour, reflectance and texture.

By comparing the arguments regarding the properties of a product's surface, aluminium's suitability as a material and by studying available finishing techniques, we can conclude that our hypothesis is valid: Surface treatments can be a versatile and sustainable approach for successfully incorporating more aluminium into consumer products and optimise these through surface design.

8. FURTHER WORK

Further development of this subject can include a more thorough mapping of available finishing techniques. Methodically exploring a wider selection of available surface treatments can be used to explore different applications of the techniques. These results can then be used to generate a system for designers consisting of strategies to create specific emotional characteristics through surface design. To achieve the proper results, it would also be beneficial to conduct a study which investigates how users react to the different finishes.

Additionally, designers can increase their application of aluminium in their consumer products. This will enable us to keep evaluating how successful the use of the material and its surface treatments really are. It can also help gain recognition of the potential aluminium has as a commercial material by users, companies and other product designers.

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