TITANIUM AND ALUMINUM: HANDLING, SOLDERING, AND ANODIZING FOR THE PRODUCTION OF HANDCRAFTED JEWELRY

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INTRODUCTION

Titanium and aluminum are non-precious metals that, due to their qualities, can be used in the production of fine jewelry. The use of these metals have very specific purposes, such as weight reduction and aesthetic possibilities. The way they are handled is different from other traditional metals used in jewelry production, and they must be dealt with in a very specific way. In this lecture, we will explore their properties and the correct ways to handle them. These properties, mainly toughness and lightness, allow us to make pieces that would be too heavy or too complicated to make with traditional metals like gold and platinum. On the other hand, another one of their particularities is that they can be anodized, which gives us more creative freedom, allowing us to create really colorful pieces.

Aluminum, origin and history:

Aluminum (Al), is the most abundant metal that can be found in the Earth's crust with 8.23%,
followed by iron with 5.63%, and magnesium with 2.33%. We must keep in mind that these are the percentages of the most abundant metals which can be extracted quickly and cheaply by humans. If we were to consider the most abundant metal on Earth as a whole, this would be iron, since the Earth's core is mainly composed of this metal.

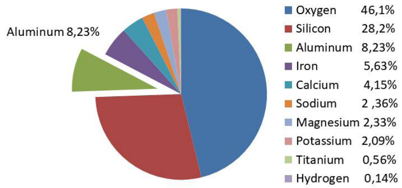

Figure 1: Elements of earth's crust (aluminum)

Aluminum is a whitish metal that is extremely light and highly resistant to corrosion. The element was identified in the 19th century, but it wasn't until 1809 that the British Humphrey Davy proposed to name it aluminum. In 1825, Danish physicist Hans Christian Oersted, discoverer of electromagnetism, succeeded in isolating the first impure aluminum samples with electrolysis. These samples have been recorded by the Royal Danish Academy of Sciences and Letters. Total isolation was achieved two years later by Friedrich Wölher, a German chemist who visited Oersted and obtained permission from him to continue his experiment. There is some controversy as to who was the first to isolate it, the Danish Orsted with his rather impure samples, or the German Wölher with a purer synthesis.

Figure 2: Hans Christian Oersted (left) and Friedrich Wohler (right)

Even with Wöhler's method, it used to be impossible to obtain large quantities of aluminum, which made it very expensive and exotic.

In 1852, aluminum was more expensive than gold. At the time, it traded for around 34 U.S. dollars an ounce, while gold traded for around 19 dollars an ounce. Aluminum extraction was very expensive in the 19th century because it is not found in pure form. Nowadays, its extraction is very profitable and it can be found at a very affordable price.

In nature, aluminum is not found in free form but in a combined form, which means it is found in other elements such as silicates. The aluminum found in these rocks cannot be extracted, so it's mainly extracted from bauxite. Between 85 and 95% of the bauxite mined worldwide is used for aluminum production. Bauxite, although also a type of rock, is found in sediment deposits in the form of clay, which facilitates the two aluminum isolation processes.

These are:

The Bayer process, from which alumina is obtained from bauxite, by dissolving this clay in caustic soda. This alumina is nothing more than aluminum oxide, and once obtained, it is passed to the second process.

In the Hall-Heroult process, the alumina undergoes a complex electrolysis process and is decomposed into aluminum and oxygen.

As I said earlier, production in the 19th century was so expensive that aluminum came to be considered an exotic, exorbitantly priced material as precious or more precious than silver or gold. At the 1855 Paris Exposition, aluminum bars were displayed alongside the crown jewels of France. Emperor Napoleon III himself had asked for aluminum tableware to entertain his guests. The apex of the Washington Monument, made by William Frishmuth, was also made of aluminum, which traded at a similar price to silver in 1884. The monument was designed by the architect Robert Mills, but it was Frishmuth who crafted the apex of the monolith. Gradually, aluminum's price went down as extraction became cheaper and easier over the years.

Its main properties are:

Malleability: The ability of a material to be formed into thin sheets without breaking. Aluminum is one of the most malleable metals that exists, and being a very soft metal, its deformation to form thin sheets requires very little mechanical effort.

Ductility: Ductile materials are those that can be stretched and formed into thin wires or wire. Aluminum is also very ductile, although less ductile than malleable. It allows us to create bars, chains and wires of different sizes and shapes.

Toughness: A material's resistance to breakage when subjected to slow deformation forces.
Aluminum has some toughness, but it is not as good as its malleability or its ductility. Though it has some resistance to bending and twisting, it will eventually crack and break.

Mechanical resistance - machinability: Being a very soft metal, it has low mechanical resistance, which is a favorable quality in terms of jewelry creation. We will not have problems drilling it, sawing it, hammering it, shaping it or finishing its surface. Even tools that normally wear down metals, such as burs, drill bits, gravers, and abrasives, will not cause excessive wear and tear with aluminum. Its finish can range from mirror polishing to any type of shading.

Weight: Aluminum is a very light metal, with a density of 2700kg/m3, approximately one third of steel's. This makes it especially useful in applications where strength is required but weight reduction is also sought.

Alloys:

As it is too soft a material, pure aluminum has very little industrial application. However, when alloyed with other elements, it can be strengthened and acquire other qualities, which vary according to the nature of the alloys used.

The seven most commonly used alloys are:

* 1000 alloys: These are 99.9% technically pure aluminum alloys, with the main impurities being iron and silicon as alloying elements. These alloys are mainly used to manufacture utensils for non-technical purposes.

* 2000 alloys: The main alloying element in this group of alloys is copper (Cu). This alloy is used especially in the manufacture of aircraft structures.

* 3000 alloys: The main alloying element in this group is manganese (Mn), which is used to strengthen the aluminum. These alloys have good workability, and they're used in the manufacture of kitchen utensils and containers.

*4000 alloys: Due to its good weldability, it is mainly used as a filler metal for welding.

* 5000 alloys: In this group of alloys, magnesium (Mg) is the main alloying element. These alloys are used in vehicle construction, including marine vehicles.

* 6000 alloys: The main alloying elements in this group are magnesium (Mg) and silicon (Si).
(Si). These alloys are used for profiles and structures in general.

* 7000 alloys: The main alloying elements in this group are zinc (Zn), magnesium (Mg) and copper (Cu). They are used to manufacture aircraft structures.

The aluminum alloys with the greatest mechanical strength are the 2000 and 7000 series, especially 2024 and 7075. The 3000 series is moderately strong and has extraordinary weldability and good workability, with 3003 standing out in this series. Along with the 3000 series, the 5000 series, especially 5052, has some of the best welding characteristics, excellent finishing qualities, and a strong resistance to saltwater corrosion. Nevertheless, the 6000 and 7000 aluminum alloy series are the most commonly used due to their wide range of applications, with 6061 and 6063 standing out above the rest.

Series	Most common alloys	Main alloy	Main qualities
Series 1000	1100-1070	None - 99% Aluminum	Best ductility, best malleability
Series 2000	2024-2011	Copper	Good machinability
Series 3000	3003-3004	Manganese	Good weldability
Series 4000	4043-4045	Silica	Best weldability, used as filler material
Series 5000	5052-5083	Magnesium	Good weldability, good corrosion resistance.
Series 6000	6061-6063	Silica-Magnesium	Most versatile, most used
Series 7000	7075-7050	Zinc	Good machinability

Figure 3: Most common aluminum alloys

Ways to work with aluminum:

When we consider aluminum's main characteristics and the different types of alloys, such as a polyvalent alloy like the 6000 series, we should not have any problems working with it except when soldering and anodizing, which we will cover in their respective sections.

The way we work with aluminum is not very different from the way we work with any other traditional metal in jewelry, like gold, platinum, and silver. In fact, it even has certain similarities in terms of ductility and malleability, although not so many in terms of toughness or weight.

This means it can be rolled, drawn, dapped, drilled, reworked, engraved, finished, polished or set without any problems. Like with any other metal, a good thing to remember when working with aluminum is to lubricate it when drilling or sawing it. Another aspect to take into account is how aluminum behaves when it is bright-cut with a polished graver. The cut surface does not maintain its shine as gold or silver would and requires a light polishing afterwards. In this respect, it is somewhat reminiscent of platinum, which reacts similarly to this process yet less noticeably.

We must plan our aluminum pieces carefully in order to save its most challenging properties. This is important to consider in order to elaborate technically feasible pieces with this material. With caution and forethought, we should be able to create any type of piece with aluminum.

Processes to which aluminum reacts differently than traditional metals used in jewelry:

Soldering aluminum is completely different from the traditional way to solder classic metals such as gold, platinum or silver.

Aluminum can be anodized, which traditional metals do not allow, although they can receive galvanic baths such as the rhodium bath, gold plating bath or ruthenium bath. In recent years, baths of bright colors have also been developed successfully. These resemble the colors achieved by anodizing a piece, but technically this is not anodizing.

Finally, in all processes where the aluminum's toughness is a key factor, it is important to avoid subjecting the aluminum to recurrent deformations in opposite directions.

Taking this into account, processes such as rolling, deep drawing, filing, drilling, etc. should be carried out in the same way as with gold, platinum or silver.

Titanium, origin and history:

Titanium (Ti) is a gray colored metal with low density and high toughness. It is very resistant to corrosion from seawater, nitric acid, hydrochloric acid, and chlorine.

In nature, titanium is always found bonded to other elements. It is the ninth most abundant element and seventh most abundant metal in the Earth's crust (fourth structural metal, behind only aluminum, iron and magnesium), accounting for 0.56% of its mass. Of the 801 igneous rock types analyzed in a study by the United States Geological Survey, 784 contained titanium, and its proportion in the soil was found to be between 0.5 and 1.5%.

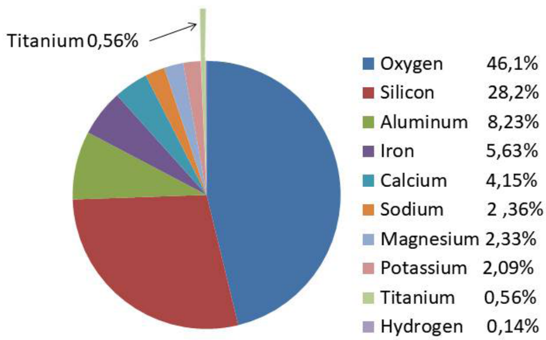

Figure 4: Elements on earth's crust (titanium)

In igneous rocks and minerals formed from the decomposition of igneous rocks, many minerals, mainly iron-bearing, contain titanium. This element is abundant in mineral deposits, mainly in the form of oxides such as rutile and ilmenite, widely distributed throughout the Earth's crust. Titanium is the metallic element with the highest toughness-to-density ratio. It is a very strong metal, with a low density and high ductility. Titanium has a density 60% higher than aluminum's, but it is twice as strong as the most common aluminum alloy (6061). It is highly resistant to corrosion, comparable to that of aluminum, and is able to resist deterioration from strong mineral acids such as sulfuric acid.

Titanium is first extracted from rutile (titanium oxide), which is abundant in coastal sands. To do this, titanium must first undergo a refining process to prevent it from reacting with substances like nitrogen, oxygen and hydrogen.

It was discovered in 1791 by English scientist William Gregor in a mine in Cornwall, Great Britain, and in 1795 by Martin Heinrich Klaproth, a German chemist who also discovered uranium, zirconium, and tellurium. It was the latter who proposed its name. There are two theories about the origin of its name. The first, the most widespread, holds that Heinrich named it “titanium” to allude to the titans of Greek mythology because of its properties. The other states that its name comes from titanos, the ancient Greek word for “white earth”, since its oxide is one of the purest whites.

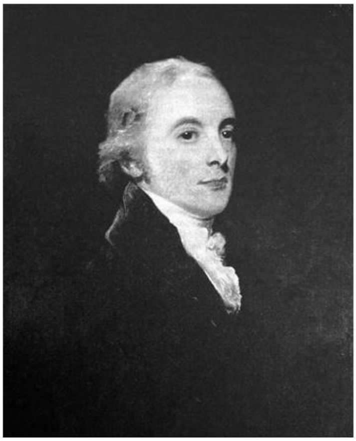

Figure 5: William Gregor (left) and Martin Heinrich Klaproth (right)

Matthew A. Hunter was the first to obtain titanium (with a purity of 99.9%) by heating titanium tetrachloride ($TiCl_4$) with sodium at 700-800°C. The Hunter process was the first industrial process to produce pure ductile metallic titanium. It was developed in 1910 by Hunter, a New Zealand-born chemist working in the United States. In the Hunter process, rutile (ore with high titanium dioxide content) is mixed with chlorine and coal-based fuel with a high carbon content. In the process, titanium tetrachloride was reduced with sodium in a steel pump at 700-800 degrees Celsius. Prior to the Hunter process, all efforts to achieve titanium metal resulted in highly impure material, often titanium nitride (which resembles a metal). The Hunter process was replaced by the more economical Kroll Method in the 1940s.

Titanium was not generally used as a metal until 1946, when William Justin Kroll developed a method to produce it industrially by reducing tetrachloride with magnesium. This method, called Kroll’s method, is still used today. In this process, the metal must be kept in an inert gas atmosphere, such as argon or helium, to prevent reaction with other elements.

The complexity of this production process explains the high market value of titanium, although it is a cheaper process than the Hunter method.

The price per ounce of titanium has been dropping in recent years, and currently stands at about 4 U.S. dollars per ounce, although prices are considerably higher when purchased in small quantities or in pre-forms to work it into bars, sheets or wires.

It is widely used in aerospace engineering and weapon manufacturing. Curiously, it is also used to create medical devices such as surgical tools and medical implants, since titanium is biocompatible and has little reaction with human tissue. It has also been estimated that it could be used to contain radioactive waste. It is possible to manufacture containers that could last up to 100,000 years as long as the process complies with a series of manufacturing conditions determined to reduce possible defects.

The Cerritos Library in California was the first public building in the United States to be clad with this material. Although the building was constructed earlier, it was remodeled between 2000 and 2002 with the addition of its current titanium cladding.

Its main properties are:

Malleability: It is a highly malleable metal which allows for the production of very thin sheets. Although it requires somewhat more mechanical strength to laminate it than aluminum, this task can be performed easily.

Ductility: Titanium is also a very ductile metal, allowing the shaping of bars, wires or wires of different shapes and thicknesses.

Toughness: This metal has excellent toughness and resistance to fatigue fracture. Titanium alloys have a good ability to keep cracks from spreading or growing larger.

Mechanical resistance - machinability: Titanium has a high mechanical resistance. It is difficult to mill and cut, due to its low thermal conductivity and the high reactivity of titanium with cutting materials. These characteristics lead to high tool wear, contamination of the workpiece with cutting material, as well as the formation of a built-up edge.

Weight: Titanium is also a light metal, with a density of 4500kg/m3, 45% lower than steel's and only 60% higher than aluminum's. Although it is not as light, it does have higher strength. Titanium has a better strength-to-weight ratio than aluminum.

Alloys:

Pure titanium occurs in two allotropic forms: alpha phase (compact hexagonal) and beta phase (centered cubic). Some elements, such as titanium, are capable of arranging their atoms in different ways while maintaining the same state; this quality is known as allotropy. Alloys of this metal are classified allotropically as alpha, alpha+beta and beta, with an approximate market utilization of 26%, 70% and 4% respectively. Ti-6Al-4V alloy, being the most common of the alpha+beta alloys, occupies 56% of the total Ti market due to an exceptional balance between mechanical strength, ductility, fatigue resistance and fracture toughness.

Although Ti alloys can be classified according to their allotropic form, they are most commonly classified by grade. The American Society for Testing and Materials (ASTM) recognizes 39 grades.

The most commonly used are as follows:

Ti grades 1, 2, 3 and 4, unalloyed, integrate the so-called commercially pure titanium with a composition of more than 99% Ti.

Ti grades 5 (Ti-Al6-V4) and 9 (Ti-Al3-V2.5) alloyed with aluminum and vanadium are alloys with good corrosion resistance and a medium level of mechanical strength.

Ti grades 7 (Ti-0.15Pd) and 11 (Ti-0.15-0.25Pd) alloyed with different proportions of palladium represent alloys with higher corrosion resistance.

The alloys with the highest ductility and malleability are alloys of grades 1 to 4, with grade 2 being the most widely used of this group. The alloys of grades 5 and 9 in particular maintain a large part of their mechanical qualities but are a little harder than the alloys of grades 1 to 4. Lastly, the alloys of grades 7 and 9 are used in situations where they are exposed to corrosive elements due to their virtues.

Grade	Most common alloys	Main alloy	Main qualities
Grade 1	Pure 0,18% O2 (Low Oxygen %)	None - 99% Titanium	Best ductility. As the level of oxygen in titanium increases, its strenght increases very slightly, and its ductility decreases.
Grade 2	Pure 0,25% O2 (Low-Medium Oxygen %)	None - 99% Titanium	
Grade 3	Pure 0,35% O2 (Medium-High Oxygen %)	None - 99% Titanium	
Grade 4	Pure 0,40% O2 (High Oxygen %)	None - 99% Titanium	
Grade 5	Ti-6Al-4V	6% Aluminum - 4% Vanadium	Most versatile, most used
Grade 6	Ti-5Al-2.5Sn	5% Aluminum - 2,5% Tin	Good weldability, good strenght
Grade 7	Ti-0.15Pd	0,15% Palladium	Good strenght, good ductility
Grade 8	Ti-8Mn	8% Manganese	Good corrosion resistance, good strength
Grade 9	Ti-3Al-2.5V	3% Alluminum – 2,5% Vanadium	Good weldability, good corrosion resistance

Figure 6: most common titanium alloys

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Ways to work with titanium:

Like with aluminum, soldering and anodizing are the most challenging parts of working with titanium, which we will see later. Apart from this, we can work with it successfully when taking certain precautions. It is also a very malleable and ductile metal, which will allow us to laminate it, draw it, and deep draw it without problems. As it has a higher toughness than aluminum, we will have more opportunities to change its shape before stress cracks or fractures appear.

On the other hand, it will be more difficult to drill, saw, or file it. As we have seen in the section about its main qualities, titanium has a low thermal conductivity. Although metals are a group of elements characterized by high thermal conductivity, titanium has a fairly low conductivity. The higher the thermal conductivity of a metal, the faster it will heat up, for example when subjected to mechanical friction, and the faster it will cool down. This implies that titanium will take longer to heat up when we work with it but will retain its heat longer, which will significantly influence how quickly our tools wear down. Also, the high reactivity of titanium at high temperatures means that the tools degrade very quickly as the reactivity increases exponentially as the temperature rises.

Surface finishing is also more expensive for these reasons. Sanding or abrasive processes with rotary tools such as micro-motors require time and patience, and it is advisable to use low revolutions (rpm) for abrasive rotary tools. For milling and cutting, it is advisable to increase the revolutions per minute in order to avoid the built-up edge if we see that this appears. Lubrication is essential to perform these tasks.

We can set stones, but we must be very careful when milling, drilling, and setting the gems. In this regard, it is more challenging to perform this task on titanium than on aluminum.

Finally, it is also possible to polish titanium. The polishing paste helps reduce friction and allows us to achieve a very good finish. It is also recommended to use low revolutions per minute for this task.

Processes to which titanium reacts differently than traditional metals used in jewelry:

As we have seen with aluminum, the soldering process of titanium is totally different and we will address it in the next chapter.

Anodizing, like with aluminum, is a process that can be done with titanium but not with gold, platinum or silver.

All processes involving frictional heating of the piece can affect our tools, and processes such as milling, cutting, or surface finishing should be performed more slowly and with lubrication whenever possible. In this respect, titanium behaves very differently from traditional metals used in jewelry.

The rest of the processes can be carried out in a similar way as if we were working with gold, silver or platinum.

Soldering:

This is the most critical process that we are going to look at when handling these two metals. Aside from being aesthetically displeasing, a poorly soldered joint seriously compromises the structural integrity and durability of a piece. This aspect is key and should not be overlooked. It is very important that we are thorough with each step and scrupulous when performing them.

Apart from this, we must always bear in mind soldering's limitations when making a piece. It is essential that we adapt the design of our jewelry pieces keeping this issue in mind and make corrections to the design if necessary. We will avoid failed executions and fragile, flimsy pieces.

Soldering is the joining or fusing of pieces by using a heat source to make the parts form a continuum. The heat source in soldering is usually a flame or laser or electric arc produced by electricity.

Different types of soldering and their suitability for each metal:

Any soldering method involving common flame torches and torch hydrogen soldering systems is not viable for jewelry making. While aluminum can be soldered using flames or rods with zinc-based filler material, these methods are impractical due to the introduction of additional materials, which compromises results during anodizing.

The fusion of pieces can only occur through heat produced by lasers or arc soldering with inert gas.

Arc soldering TIG/GTAW

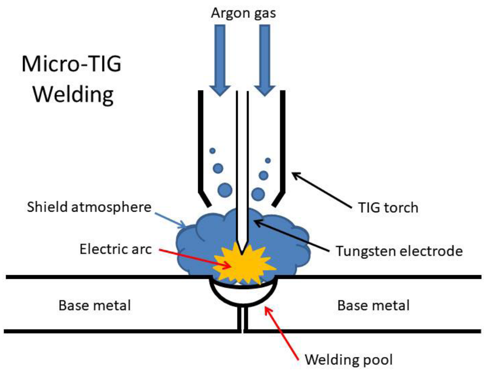


Figure 7: Micro-TIG welding

Gas Tungsten Arc Welding, known as TIG (Tungsten Inert Gas) or GTAW (Gas Tungsten Arc Welding), stands out as the most common and efficient industrial method for soldering, as it effectively melts pieces together. This method allows manual addition of filler material during soldering.

Another prevalent industrial method involves melting a filler metal in the weld seam, using a wire feeder through the welding gun (MIG/MAG welding, also known as GMAW or Gas Metal Arc Welding in some regions). However, this method is not used in jewelry, as the TIG/GTAW system already allows for manual filler material addition. The filler metal must approximately match the melting point of the parts to be joined.

Though there are specialized industrial TIG/GTAW welders, including precision and small-caliber options suitable for jewelry, Pulse Arc Welders, Micro-Welders, or Micro-TIG Welders are generally considered to be the most suitable for the jewelry sector. These systems, leveraging the same principles as industrial systems, enhance precision in jewelry tasks.

These systems use the same concept as industrial systems. The arc required for soldering is a burst of electricity between the tungsten electrode and the piece to be soldered. The arc is generated when a large enough voltage pulse is created between the pieces. This can be accomplished by contact ignition with the electrode or by foot pedal.

In Micro-TIG systems, inert gas must be used to establish a protective atmosphere in the weld zone, just like in industrial TIG welding practices. Ambient gasses pose a risk of contaminating or reacting with molten metal and contributing to slag and impurities, resulting in an inefficient, brittle, and uneven weld bead. Shielding gasses, particularly pure argon in Micro-TIG welding practices, play a vital role by isolating the weld zone from the surrounding atmosphere, ensuring superior quality, minimal contamination, and a uniform joint.

The shielding gas also plays an important role in protecting the area where the metal melts and solidifies. In this case, argon safeguards against oxidation, contaminants, and air humidity, mitigating risks of joint weakening, reduced corrosion tolerance, or the development of porous areas.

Laser beam welding

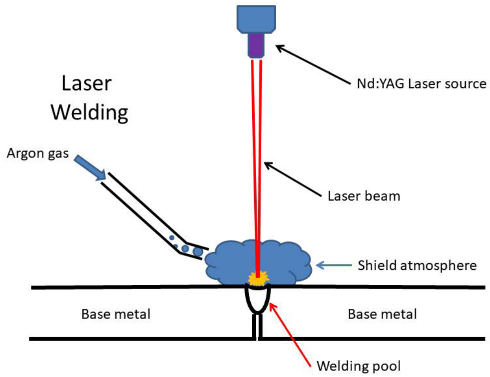


Figure 8: Laser beam welding

Another effective system for joining aluminum and titanium pieces is laser welding, abbreviated as LBW (Laser Beam Welding). This method utilizes the energy from a laser beam to fuse parts together, allowing flexibility with or without filler material. Laser welding is typically carried out in the presence of a protective gas, commonly helium or argon, with argon being widely favored in jewelry applications. Similar to the TIG/GTAW system, the use of shielding gas is imperative to achieve an effective joint. Notably, laser soldering stands out as a soldering method without direct contact with the energy source responsible for metal melting.

The laser employed in this welding type emits sufficient energy within a confined space to melt the material we're working with. Comparatively, the transition zone between the melting area and the surrounding metal is notably smaller in laser soldering than in the TIG/GTAW system. Though the TIG/GTAW system already boasts a relatively compact transition zone, laser welding further refines this into an even more delimited transmission area.

There are two efficient laser technologies for industrial welding: gas lasers and solid-state lasers. Gas lasers utilize a mixture of CO2, nitrogen, and helium as an active medium, which is also common in laser cutting. Solid-state lasers, employing a solid active medium, feature the Nd:YAG system as the most common type due to its outstanding qualities.

The Nd:YAG system (Neodymium-doped Yttrium Aluminium Garnet) holds widespread use in the jewelry industry, powering virtually all laser soldering machines designed for jewelry creation. Today, a diverse range of brands and models cater to various preferences and needs. These span from entry-level machines without argon gas at an economical price to more professional ranges with argon gas at a higher cost. Over the years, the price has significantly dropped due to more cost-effective and efficient manufacturing processes. This evolution has given rise to models that are not only more technologically advanced but also more efficient and compact, providing a broad spectrum of options for all tastes in the industry.

Best soldering methods for each metal:

Answering this question in a general sense is challenging due to various factors. Factors such as the alloy type, surface conditions, cleaning and preparation, soldering angle, the solderer's expertise, or personal comfort with a specific system all influence the choice of soldering method.

When considering weld penetration and making other broad generalizations, the Micro-TIG system proves slightly more effective for soldering both titanium and aluminum compared to laser systems of the same price. However, it's essential to note that laser systems offer the advantage of soldering in narrow areas inaccessible with Micro-TIG, among several other benefits we'll discuss later.

Advantages and disadvantages of each type of technology:

The Micro-TIG system achieves substantially deeper weld penetration than the laser system.

In the laser system, the joint is more concentrated compared to the Micro-TIG system. The Micro-TIG system produces more residual heat than the laser system, causing a larger surface area to be heated. If the metal alloy being soldered has been heat-treated or tempered, the metal surrounding the joint may lose some properties. In contrast, the laser system produces almost zero residual heat, allowing soldering in proximity to gems, hinges, or clasps, making it especially useful for repairs. In this regard, the laser system comes out on top.

Micro-TIG soldering often creates a superficial dark halo of impurities and residues around the joint. This halo is easily removable with a light brushing and cleaning. Laser soldering, in contrast, is considerably cleaner. While a halo phenomenon may occur with laser soldering, it is much less noticeable.

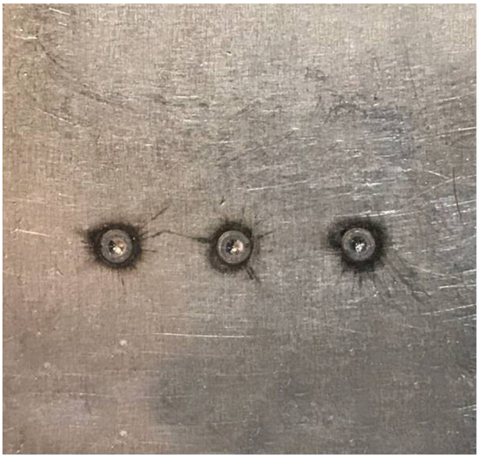


Figure 9: Image of the black halos preoduced by the welding point

The deformation of the surface in the soldering zone is more pronounced when performing spot or bead soldering with Micro-TIG. This results in a small cavity surrounded by a regrowth of the surrounding area. A small cavity is also produced when using a laser, but its depth and diameter are significantly reduced, with minimal regrowth of the surrounding area.

Laser soldering systems eliminate the need for direct contact with the emitting source responsible for creating the weld spot or weld bead. Essentially, it is a form of "remote" soldering, enabling the joining of materials in highly inaccessible locations. These areas may be challenging for the Micro-TIG system handpiece to reach, including very narrow spaces, locations with tight angles, or extremely confined interiors. This capability stands out as one of the most compelling advantages of laser soldering.

The learning curve with Micro-TIG systems is faster compared to the laser system. It takes less time to learn the necessary parameters and soldering techniques.

Maintenance for Micro-TIG systems is straightforward, while laser systems require slightly higher maintenance and periodic recalibration.

Lastly, in terms of cost, laser systems tend to be quite expensive. Micro-TIG machines, available at a similar price point, often surpass their laser counterparts in terms of joint robustness and soldering quality. Lower-cost lasers typically lack argon gas and fall short of the capabilities found in high-end professional lasers, which, in turn, can be quite costly.

These are the primary advantages and disadvantages of the two soldering systems, and the choice depends on individual needs and preferences.

Preparation and cleaning of the surfaces to be soldered:

Before cleaning, surface preparation is crucial. Ensuring a uniform surface is vital, as soldering along a surface with abrupt texture changes or rough spots can pose problems.

Proper surface preparation, often achieved through grinding or sanding techniques, creates a matte surface that enhances part joining, resulting in a stronger and more durable joint. It also helps avoid side effects like porosity and imperfections.

It is important to understand that the surfaces of these pieces are frequently exposed to contaminants like dust, dirt, or grease. These impurities have the potential to disrupt the seamless fusion of base metals, leading to subpar soldering quality. Such interference may contribute to defects or imperfections and compromise a joint's strength.

Proper cleaning is the key to a successful soldering operation. Surface cleanliness and preparation can also affect the appearance of the final joint.

The use of alcohol or acetone is advisable. Pure isopropanol/isopropyl alcohol (99.9%) serves as an excellent cleaning agent. Not only does it function well as a grease remover, addressing residual grease or oil from fingerprints, but it's highly pure, which ensures no residue is left behind, effectively eliminating surface dirt and foreign particles.

Application with a streak-free cloth or blotting paper is recommended. After cleaning, parts should not be touched with bare fingers.

The sequence to follow is: piece inspection, surface preparation, cleaning and soldering, finishing, and final cleaning.

In summary, preparing the surface before soldering is a critical step in achieving a safe, strong, and flawless joint. Removing contaminants and creating a clean, proper surface is essential for a successful soldering operation.

Soldering, finishing and preparation for anodizing:

Before soldering, several safety considerations must be taken into account. Eye protection is crucial if the equipment lacks binoculars, and wearing a mask to prevent inhaling fumes and toxic gasses produced during soldering is necessary. Adequate ventilation is also advisable. Ensuring equipment is in optimal condition and maintaining a clear workspace contributes to creating a safe environment.

Conducting a preliminary test is advisable to determine if the power and duration parameters are suitable for the type of metal to be soldered, as well as for the specific joint type and the thickness of the pieces.

The parameters to regulate include:

- Power
- Duration
- Tip thickness, adjustable in laser and TIG (by changing the thickness of the tungsten electrode)

Starting with lower power and duration parameters and gradually increasing them is always recommended. This approach ensures that the configuration allows for a good range of penetration at the junction of the two pieces, preventing material loss due to excessive fusion. This practice also mitigates risks, especially when working in areas close to gemstones.

Another crucial factor is the soldering angle. Results may vary slightly depending on the soldering angle chosen. When adding filler material, using a narrower angle and positioning the melting point in front of the filler material wire is advisable. Placing it just before the wire ensures that the molten material from the wire is deposited in the desired area of the base metal. Additionally, when incorporating extra material into the filler, the power must be adjusted to accommodate the increased material and the target area. Regulating power is essential not only based on the thickness of the piece to be soldered but also on the thickness of the filler wire.

Before creating the weld bead, it's imperative to secure the pieces with 2, 3, or 4 tack welding points, evenly distributed along the intended bead path. This not only streamlines the task but also allows for the assessment and adjustment of the pieces positioning before welding. Rectifying the position becomes more manageable with a few tack welding points compared to a complete weld bead.

Figure 10: Image of an example of tack welding

The type of joint we choose also plays a crucial role, with some joints, like the T-joint, requiring a slightly lower soldering angle technique for successful execution.

The soldering pattern is also important in bead creation – excessive distance between points results in a weaker joint, whereas minimizing the distance enhances a joint's robustness.

Irregular weld bead pattern

Good weld bead pattern

Figure 11: Soldering patterns

The key to achieving a proper joint depends on a combination of:

- Good surface preparation and cleaning
- Adequate equipment condition
- Correct power and duration parameters
- Appropriate soldering angle and technique
- Efficient weld bead pattern

Upon completing the soldering process, it is essential to eliminate potential impurities, dark halos, and inspect for any irregular growths. Cleaning by ultrasonic bath or with steam is recommended.

Lastly, it's important to mention that soldering aluminum is trickier than soldering titanium. Large pores may show up, and the joints can become brittle, sometimes leading to cracks. This becomes more pronounced when dealing with aluminum alloys that don't solder well.

These are the basics you need to grasp when soldering these metals. Like with any skill, practice is key. With time and patience, you'll develop the necessary expertise to carry out this task successfully.

Anodizing:

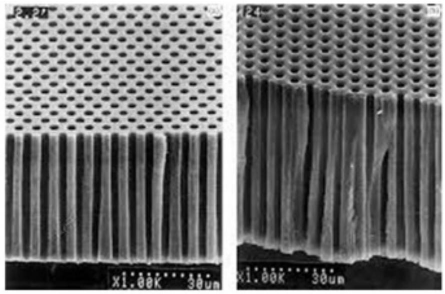
Anodizing is an electrolytic immersion process that involves passing an electric current through an electrolyte between two conductive electrodes known as the anode and cathode. The reaction occurs when we connect these electrodes to an energy source. The cathode is always connected to the negative pole of the source, while the anode is connected to the positive pole.

This principle forms the basis for anodizing both aluminum and titanium, albeit with significantly different processes for each respective metal.

It's crucial to note the use of hazardous chemicals in this process, which requires protective measures such as eye protection, hand protection, and a mask. It is imperative to perform these tasks in a well-ventilated environment, preferably with fume extraction, and avoid inhaling any vapors during the anodizing process. We must also use extreme caution when handling electrical currents during this process. No precautionary measure is too small.

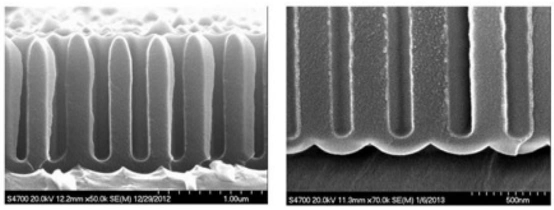
Basics of aluminum anodizing:

In the case of aluminum, the anodizing process serves to enhance the thickness of the naturally occurring surface oxide layer. This technique enables the controlled artificial expansion of the natural aluminum oxide layer (alumina). The resulting layer typically ranges in thickness from 5 to 25 microns (micrometer). Another process, referred to as hard anodizing, achieves thicknesses exceeding 100 microns, designed for situations with severe corrosion concerns. However, for jewelry applications where pieces aren't exposed to extreme corrosion, the hard anodizing process is unnecessary. One notable advantage of the aluminum anodizing process is the possibility to dye the oxide layer in a subsequent two-step procedure (dyeing and sealing). The oxide layer exhibits high porosity and absorbent capabilities within its cavities, accommodating the dye. Following the staining phase, the sealing process is essential. It ensures the closure of these pores, encapsulating the color within, providing durability and preventing pigment loss from friction.



Photograph of the broken edge of the anodic aluminum oxide

Image by: Anodic aluminum oxide microchannel plates
Authors: A.Govyadinov, I.Emeliantchik A.Kurilin
Institute of Electronics Minsk Belarus
National Center for Particle and High Energy Physics, 22004Minsk, Belarus



Photograph of a cross section of the growth of the alumina layer

Image by: Control of the Nanopore Architecture of Anodic Alumina
Chanyoung Jeong , Jeki Jung , Keith Sheppard and Chang-Hwan Choi
Department of Advanced Materials Engineering, Dong-eui University Korea
Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ, USA
Department of Chemical Engineering and Materials Science, Stevens Institute of Technology, Hoboken, NJ, USA

Figure 12: Image by: Anodic aluminum oxide microchannel plates Authors: A.Govyadinov, I.Emeliantchik A.Kurilin Institute of Electronics Minsk Belarus National Center for Particle and High Energy Physics, 22004Minsk, Belarus
Figure 13: mage by: Control of the Nanopore Architecture of Anodic Alumina Chanyoung Jeong , Jeki Jung , Keith Sheppard and Chang-Hwan Choi Department of Advanced Materials Engineering, Dong-eui University Korea Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ, USA Department of Chemical Engineering and Materials Science, Stevens Institute of Technology, Hoboken, NJ, USA
Steps of the aluminum anodization process

SANFELIX

Cleaning and surface preparation:

Because anodizing does not conceal surface defects, it is crucial to ensure that the surface is devoid of imperfections and exhibits a uniform finish. A thorough inspection at this stage can prevent potential issues, sparing the need to repeat the entire process. The surface can be either matted or polished.

The presence of contaminants or impurities, including fingerprints, can disrupt the formation of the anodic coating. Prior to anodizing, it is recommended to chemically strip the piece using sodium hydroxide (caustic soda). A solution containing 5 to 30% sodium hydroxide per liter of water is adequate for preparing the surface. The immersion duration will vary based on the concentration of caustic soda in the solution, typically ranging from 3 to 6 minutes as a general guideline. Distilled water should be used for the solution. Following immersion, the piece should be thoroughly rinsed with abundant running water and rinsed once more in distilled water before proceeding with the anodizing process.

Aluminum anodizing:

The piece to be anodized will always act as an anode, and we must hold it with a titanium wire if possible, always connected to the positive pole of our power supply. As a cathode, we will use an aluminum plate (lead is not recommended due to its toxicity), always connected to the negative pole. The electrolytic solution or bath should have a concentration of 15-20% sulfuric acid per liter of deionized water. The tank containing the electrolytic bath should be made of sulfuric acid-resistant plastic. Polypropylene (PP), for example, would be a good example, although there are other plastics resistant to sulfuric acid.

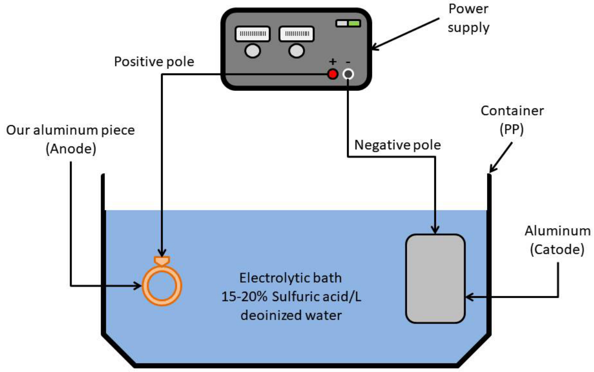


Figure 14: Aluminum anodizing

The thickness of the aluminum oxide layer to be formed varies according to the electric current, or amperage, and the duration of time to which the piece to be anodized is subjected. We will always work at a constant amperage, since the voltage will vary as the volume of the anodic layer increases. This is why it is important to work with a constant current instead of a constant voltage.

As a rule of thumb, we will use the formula of 1.5 Amp per 100 cm2 of the surface area of our piece, with a duration of 60 minutes and a bath temperature of +20ºC.

For example: If our piece has a surface of a cube of 5cm3, we would have to calculate: 5cm x 5cm x 6 sides = 150cm2. Applying the above formula would be 150cm2 / 100cm2 x 1.5Amp = 2.25Amp for 60min.

These values are approximate. If we have doubts about the total volume of our piece, it is always better to anodize for a longer period of time than to do it for a shorter period of time, as the time varies slightly depending on the alloy used and the geometry of the piece.

Once the piece has been anodized, it should be rinsed in plenty of running water for a few minutes and then rinsed again in deionized water before coloring.

Aluminum immersion coloring:

Pigments are available in specialized stores for aluminum anodizing. The staining of aluminum varies according to the concentration of pigment in the dye solution, the temperature of this solution, and the time interval that the anodized part remains in the immersion. As a general rule, a concentration between 1 to 10 grams of pigment per liter of water is sufficient.

We will always use deionized water for the staining baths; tap water is not suitable for this task due to its impurities, which would alter the solution and affect the result and final quality. We must rinse the piece under abundant running water and then in distilled water before immersing it in the staining bath. Heating the staining solution is the best way to ensure good penetration of the color into the porous alumina layer. Generally, depending on the stain, 30 to 60 degrees Celsius is sufficient to achieve this goal. Personal testing and experimentation are advised.

The duration of the dye bath generally comprises an interval of between 5 to 20 minutes. Shorter immersions achieve very soft stains, while longer immersions achieve fully saturated stains. We can adjust this by shortening or lengthening this time interval.

All these values and ranges are indicative; we must always make sure to follow the manufacturer’s recommendations.

Sealing:

This part is essential to achieve a durable anodized surface and to retain the dye bath inside the alumina layer. The process is very simple; we must immerse the piece in boiling water for 60 minutes. This will close the pores of the surface, encapsulating the color inside. It is recommended to use distilled water for this task, as tap water can cause imperfections in the final result.

Basics of titanium anodizing:

The principle behind titanium anodizing is the same as described for aluminum. It involves the controlled thickening of the titanium oxide layer (TiO_2) through an electrolytic bath process, where the titanium part acts as an anode. The thickness of the titanium anodic layer ranges from 30-50 nanometers to 2 microns (2000 nanometers). This is substantially less thickness than what we can achieve with aluminum anodizing.

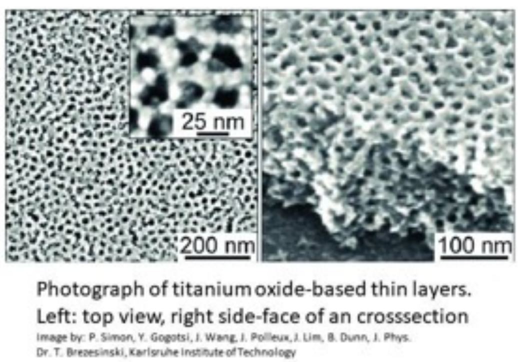


Figure 15: Photograph of titanium oxide-based thin layers, top view (left) and cross section (right)
Image by: P. Simon, Y. Gogotsi, J. Wang, J. Polleux, J. Lim, B. Dunn, J. Phys. Dr. T. Brezesinski, Karlsruhe Institute of Technology

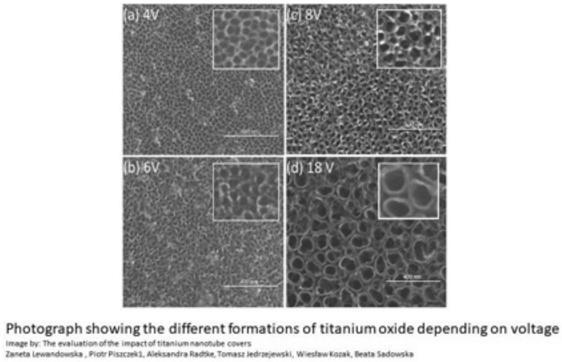


Figure 16: Photograph showing the different formations of titanium oxide depending on voltage.
Image by: The evaluation of the impact of titanium nanotube covers Zaneta Lewandowska , Piotr Piszczek1, Aleksandra Radtke, Tomasz Jedrzejewski, Wiesław Kozak, Beata Sadowska

Unlike aluminum, titanium undergoes a color change during the anodizing process, eliminating the need for a subsequent coloring step. This results in a one-step process, anodizing, as opposed to the three-step process for aluminum: anodizing-dyeing-sealing.

The color change in titanium is due to the modification of the properties of the titanium oxide layer. It is not the result of pigments or dyes but rather a phenomenon known as color interference experienced by light rays hitting the coating. The oxide layer has the ability to reflect, refract, and absorb light. When light strikes the surface, a small part is absorbed, and the remaining part is reflected back into the oxide layer. A phase shift of the light occurs due to the multiple reflections, creating an iridescence effect through the diffraction of light. This phenomenon is similar to what we observe in some animals, insects, meat, or oil stains on asphalt.

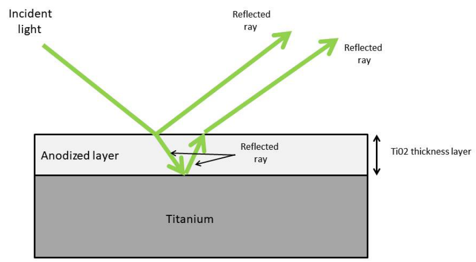


Figure 17: Titanium color interference

The degree of light absorption and the proportion of light reflection depend on the thickness of the coating. The color of the coating results from the interference of all reflected light waves. The appearance of colors formed in titanium primarily depends on the voltage to which the piece is subjected and the electrolyte used.

Steps of the titanium anodization process:

Cleaning and surface preparation:

The preparation of titanium for anodizing closely resembles the preparation for anodizing aluminum. Any imperfections present in our piece will not be concealed by the anodizing process. In the case of titanium, these imperfections are even less concealed compared to anodizing aluminum, since the anodic layer of titanium barely increases in thickness. This is why, coupled with its lower hardness, the anodic layer of titanium exhibits lower resistance to abrasion than the anodic layer of aluminum.

The removal of contaminant traces such as impurities and grease is crucial. Chemical stripping is carried out for this purpose, for which we traditionally use hydrofluoric acid. However, due to its high toxicity and the dangers associated with it, it is advisable to avoid hydrofluoric acid for stripping. There are substitutes available on the market for chemical stripping that are nearly as effective as hydrofluoric acid but considerably less hazardous and environmentally friendly. Following the manufacturer's recommendations is essential in this regard.

Upon completion of the chemical stripping process, thorough rinsing with running water and deionized water is necessary. The piece will then be prepared for the subsequent anodizing process.

Titanium anodizing:

The process is similar to aluminum anodizing, with a change in the composition of the electrolyte and cathode material. The titanium piece to be anodized will act as an anode, suspended with a titanium wire, always connected to the positive pole of our power supply. As the cathode, we will use a stainless steel plate, always connected to the negative pole. The electrolyte solution or bath should have a concentration of between 20-25% sulfuric acid per liter of deionized water. Alternatively, good results can be achieved by substituting sulfuric acid with a concentration of 10-15% trisodium phosphate per liter of water or the same proportion of sodium bicarbonate (also known as baking soda). These last two options are highly recommended to avoid risks. The temperature of the bath should also be around 20ºC. As a container for the electrolyte, we will also use polypropylene (PP).

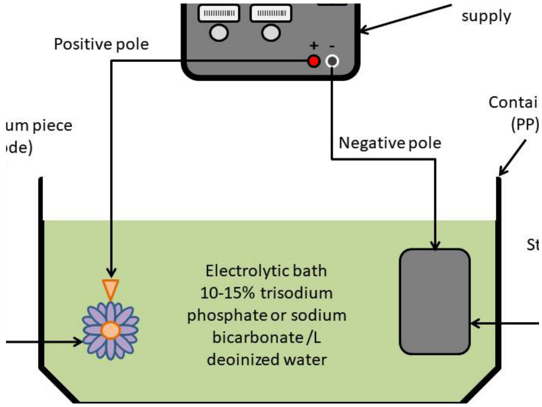


Figure 18: Titanium anodyzing

The “color” (which is actually a diffraction of light, as we have seen before) varies depending on the voltage to which we submit the piece. The voltage ranges from 5V to 110-120V. Our power supply should allow us to work with constant voltage and regulate the amperage according to the indicated voltage. The anodizing time is short due to the low thickness of the titanium oxide layer. Although diffraction appears at the moment of applying the voltage, it is advisable to sustain the anodizing for a few minutes to ensure that the anodic layer forms properly.

Once the piece is anodized, we will perform a rinse with tap water and another with deionized water.

Sealing:

No subsequent sealing is necessary, As there is no coloration by dye there is no risk of pigment loss, Although immersing the piece in boiling water for 30 min we will manage to close the pore, this is not entirely necessary.

Main differences in anodizing titanium and aluminum:

The anodizing process of aluminum involves much more time and steps. Titanium anodizing is much faster and less expensive.

Aluminum anodizing is more resistant. It can be colored afterwards.

Titanium anodizing creates a very thin protective layer. In fact, it is more decorative than resistant. The "coloring" of the surface occurs at the same time as the anodizing.

In aluminum anodizing, the thickness of the anodic layers varies according to the parameters: current density, temperature, surface area, solution volume and immersion time.

In titanium anodizing the thickness of the anodic layer hardly varies beyond 2 microns.

The aluminum oxide layer is generally much thicker and harder, which favors resistance to surface abrasion.

The titanium oxide layer is much thinner and although it does increase its resistance to corrosion, it does not increase its hardness, and is therefore less resistant to abrasion.

The staining of aluminum is much more controllable than the "color" that we can get with titanium anodizing, as there are many more variants that we can control to get the result we want, varies depending on the concentration of pigment, the temperature of this solution and the time interval that the piece remains in the immersion.

Colors and range of tones:

Aluminum:

We can dye anodized aluminum in any color except pure white.

Currently, no white dyes capable of penetrating the anodic layer have been developed. Any white aluminum we see will be painted aluminum and not anodized. The closest we can get to white is anodizing the aluminum without the subsequent dyeing process, resulting in a slightly dull silver color, a little whiter than natural aluminum. Removing the white allows us to achieve the whole spectrum of colors, including black and gold.

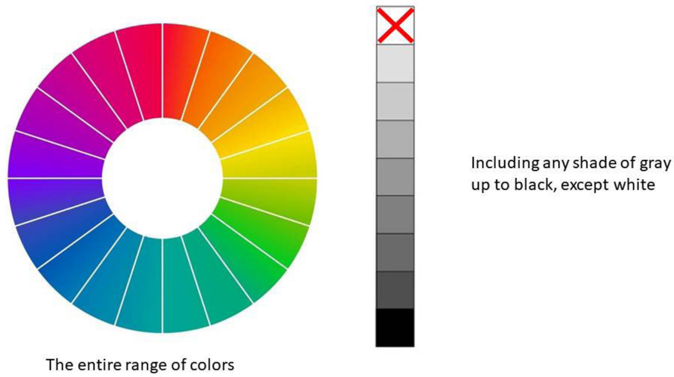


Figure 19: Aluminum color chart

By varying the saturation of the dye and the immersion time, we can achieve a wide range of shades within the same color. Additionally, since anodizing involves the penetration of the pigment inside the metal itself and not a layer of paint superimposed on the surface, the texture given to the surface will also influence the appearance of the color of our piece.

It is also possible to create color gradients in the same piece by controlling the immersion times and immersing different parts of our piece in different dyes.

Titanium:

Due to the specific color interference properties discussed earlier and the absence of subsequent coloring with pigments, there are some limitations.

White and black are not achievable (with electrolytic anodizing process), nor are red and a saturated orange. While colors close to orange are possible, they tend to have a strong pinkish dominant. On the other hand, there is a broad spectrum of blues, violets, purples, turquoises, and greens, offering a variety of attractive options. Yellows/golds and bronze/brown colors can also be achieved, although they might appear more muted and less vibrant compared to the aforementioned colors.

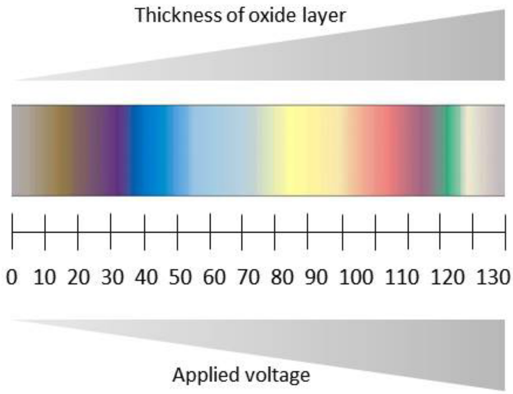


Figure 20: Titanium color chart

Although titanium does not offer as many diverse colors as aluminum, its unique beauty, particularly the distinctive iridescence, gives titanium pieces a one-of-a-kind appearance.

Durability:

Anodizing serves as a protective coating, and its resilience can be affected by certain actions. Notably, rubbing and friction with hard objects can contribute to the degradation of this coating.

The longevity of anodizing is not primarily determined by the passage of time but rather by the extent of wear and tear that the parts undergo. Consequently, with careful handling, anodizing can help maintain a piece's integrity indefinitely.

It's essential to note that aluminum anodizing exhibits significantly greater resistance to abrasions, scratches, and friction compared to titanium anodizing. This enhanced durability in aluminum results not only from the thickness achievable during anodic layer formation, which is notably more substantial than in titanium, but also due to the toughness of the anodic layer. Conversely, titanium anodizing is comparatively less resistant to scratching.

Besides usage, factors such as poor execution in the anodizing process, the pre-anodizing stage, or in the sealing process for aluminum can contribute to a potential decrease in the durability of the treated parts.

Conclusion:

The concepts and steps outlined here, though presented in a schematic manner, provide a comprehensive understanding of these two metals – how to work with them, their virtues, their flaws, proper soldering techniques, and the anodization process.

With practice, we can work with these metals much like any other familiar metal in our repertoire. Here we can see some examples:

Figure 21: Arturo Sanfelix, Yellow gold (750) with yellow sapphires and diamonds, heart cut garnets with pink sapphires, purple and fuchsa titanium.

Figure 22: Arturo Sanfelix, Yellow gold (750), red aluminum with pink sapphires, blue topaz and white gold with diamonds.

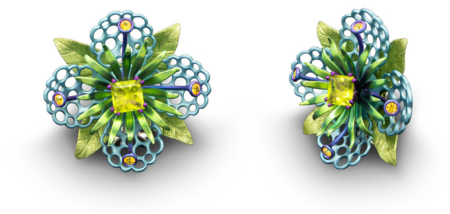


Figure 23: Arturo Sanfelix, Blue and Green aluminum, purple tianium with yellow sapphires and green titanium with princess cut peridots.

Fortunately, an impressive technology for direct metal 3D printing (DMLS/SLM) is available, enabling the fabrication of gold, platinum, aluminum, and titanium, among other materials. Embracing such advancements professionally proves advantageous. This process proves particularly helpful in piece creation, eliminating the need for manual manipulation and soldering. Nevertheless, even if manual soldering is not part of our immediate practice, understanding the process is still valuable.

A key takeaway is that the use of these metals serves a specific purpose – providing pieces with exceptional robustness while maintaining a remarkably low weight. This capability allows for the creation of a brooch that, in gold, would be excessively heavy, or large earrings that would be more comfortable to wear. Despite their advantages, aluminum and titanium are not meant to replace the classic metals traditionally used in jewelry. While these metals offer additional creative possibilities due to their strength-to-weight ratio and chromatic capacity, they lack the symbolism and tradition associated with precious metals. Gold, for instance, possesses an aura in jewelry that these metals may never fully attain. However, this isn't an absolute rule, and we can employ these metals solely for their vibrant appearance, irrespective of their physical properties. Ultimately, jewelry is an art form, and the jeweler is the one who determines what is most suitable for their piece.