MANUFACTURING EXPERIENCES IN GREY & BLACK TITANIUM JEWELLERY

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Background Study

Even prior to the onset of the pandemic, independent luxury-goods wholesalers across Europe, many of which constituted small, family-owned boutiques, alongside several major North American luxury department stores, had been encountering challenges. This was partly attributed to luxury brands progressively shifting towards vertical integration over the past two decades and, more recently, the burgeoning influence of e-commerce. This ongoing crisis might exacerbate their struggles, potentially leading to closures. The ramifications could extend beyond brands yet to fully embrace a vertically integrated distribution model, affecting emerging brands reliant on wholesale avenues to reach new customers and fund the expansion of their full product lines.

To weather these challenges, wholesalers may resort to aggressive commercial tactics and discounting strategies, which could, in the medium term, compromise the luxury positioning of brands lacking a concession model.

Luxury enterprises ought to meticulously evaluate, on a category-by-category and product-by-product basis, where the impact of these changes is most likely to be keenly felt.

As consumer behaviour adapts to lockdowns and physical-distancing measures, discernible shifts in purchasing patterns are emerging. For instance, some luxury entities observe that high-end and low-end luxury items are displaying more resilience in terms of sales compared to those positioned in the mid-range. This trend might stem from a combination of "revenge spending"—indicating a surge in demand for luxury goods during or post-crises—and a desire among consumers to maximize value by investing in practical items.

In contrast to the luxury market figures of 2019 and 2020, sales of perfumes and cosmetics experienced a 15% decline, while clothing and accessories witnessed a 20% decrease.

Why Companies Entered Into Titanium Jewellery?
Companies have ventured into the realm of titanium jewellery for several reasons, drawn by the numerous advantages and distinct properties it offers. Here are some key reasons why titanium jewellery has become a sought-after choice:

- Durability: Titanium boasts exceptional durability, resist ing scratches, dents, and deformation. This ensures that jewellery retains its original look for an extended period.
- Hypoallergenic Nature: Being hypoallergenic, titanium is ideal for individuals with sensitive skin or metal allergies. It rarely triggers skin reactions, unlike metals such as nickel or brass.
- Lightweight Design: Its incredibly light nature adds comfort, particularly beneficial for larger or intricate jewellery pieces like bracelets or statement necklaces.
- Corrosion Resistance: Highly resistant to corrosion and tarnishing, titanium jewellery remains unaffected by moisture or sweat, preserving its appearance over time.
- Biocompatibility: Used in medical implants due to its biocompatibility, titanium is safe to wear against the skin, minimizing adverse reactions or sensitivities.
- Low Maintenance: Requiring minimal upkeep, titanium jewellery can be cleaned easily with mild soap and a soft cloth, retaining its shine without regular polishing.
- Modern Appeal: Titanium, especially in shades of grey and black, complements modern and minimalist jewellery designs, offering a sleek and stylish appearance.
- Longevity: With its durability and resistance to wear, titanium jewellery often lasts a lifetime, serving as a valuable and enduring investment.
- Colour Variations: Advanced surface treatments and coatings allow for a spectrum of colours and finishes, enabling unique and customizable jewellery options.
- Affordability: Despite its quality, titanium is often more budget-friendly than traditional precious metals like gold or platinum, attracting those seeking high-quality jewellery at a reasonable price.

In essence, titanium jewellery presents a compelling mix of durability, hypoallergenic properties, contemporary aesthetics, and low maintenance. These attributes make it an excellent choice for individuals seeking enduring, stylish, and comfortable jewellery options.

Titanium Material Adaption In Jewellery After Covid-19

The adaptation of titanium in jewellery-making has seen a rise for multiple reasons, and its integration may further escalate in the aftermath of COVID-19. Here's a perspective on why this trajectory might continue or amplify:

- Evolved Preferences: The pandemic has reshaped consumer behaviour and tastes. There's a likelihood of a tilt toward more streamlined and practical designs. Titanium's sleek, contemporary look and its versatility to embody minimalist designs align with potential post-pandemic inclinations.
- Value and Accessibility: Titanium boasts durability while being comparatively lighter and more cost-effective than traditional jewellery metals like gold or platinum. Amid enduring economic uncertainties post-pandemic, its affordability may entice consumers seeking value-driven purchases.
- Technological Progress: Advancements in technology facilitate intricate and innovative designs using titanium. This may broaden the spectrum of titanium jewellery, appealing to a wider audience with varied creative designs.
- Environmental Awareness: Growing environmental concerns prompt consideration for sustainable choices. Titanium, an abundant and eco-friendly metal, could allure consumers seeking environmentally conscious jewellery options.
- Fashion and Trends: Fashion often responds to significant societal shifts. Increased prominence of titanium jewellery by designers and influencers might spur consumer interest and widespread adoption.

The post-pandemic landscape may witness shifts in consumer preferences, potentially contributing to a heightened uptake of titanium in the jewellery sector. However, market dynamics, consumer decisions, and a medley of other factors could unpredictably influence these trends.

Sunjewels Ventures Into Titanium Mastery

In today's competitive market, meeting customer demands for unique patterns on titanium materials has become a pivotal focus for companies. With an increasing emphasis on personalized and distinct designs, customers often seek intricate and custom pat-

terns etched or machined onto titanium surfaces. Recognizing this growing trend and the need to offer specialized solutions, Sunjewels has embarked on an extensive Research and Development initiative exploring various titanium material grades.
Initially, the R&D efforts concentrated on titanium Grade 2 (commercially pure titanium) and Grade 5 alloys (Ti-6Al-4V), both known for their unique properties and widespread use in various industries. The properties of titanium grade 2 & grade 5 are as follows:

Table 1: Titanium Material Properties

	Parameters	Grade 2	Grade 5
Physical Properties	Density (g/cm3)	4.51	4.43
	Melting Point (°C)	1660	1704
Mechanical Properties	Tensile Strength (MPa)	485	950
	Yield Strength (MPa)	345	880
	Elastic modulus (Gpa)	105 - 120	113.8
	Elongation at break (%)	28	14
	Hardness (HV)	160-200	349
Thermal Properties	Thermal expansion co-efficient (µm/m°C)	8.6	9
	Thermal conductivity (W/mK)	21.97	7.2

Titanium Material Sourcing

During the crucial Research and Development (R&D) stages focusing on titanium materials, Sunjewels undertook a meticulous process in sourcing the ideal titanium for their innovative projects. Sunjewels prioritized sourcing from reputed and certified suppliers, ensuring the titanium material met stringent quality standards and specifications necessary for their R&D endeavours. Thorough assessments were conducted on various aspects including material composition, purity levels, and conformity to industry-grade standards. They sought materials that offered the best balance between machinability, durability, and surface finish to meet the specific requirements set forth in their R&D objectives.

Sunjewels Strategic Beginnings with Titanium Grade 2

In pursuit of cost-effectiveness and initial feasibility, Sunjewels embarked on their titanium machining journey by primarily focusing on Titanium Grade 2. Recognized for its excellent machinability and relatively lower cost compared to other titanium grades, Grade 2 presented an attractive entry point for Sunjewels exploration into titanium-based projects.

Microstructures of Grade 2 Titanium

The presence of the alpha phase in Grade 2 titanium can contribute to a grainy or textured surface appearance after finishing processes.

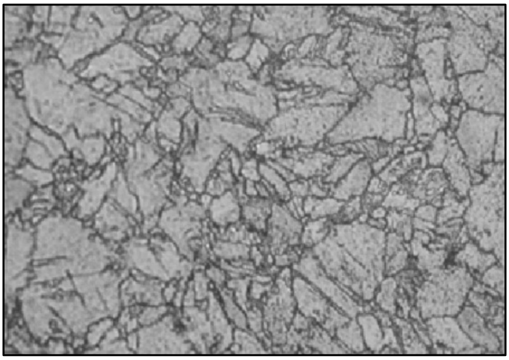

Figure 1: Microstructure of Titanium Grade 2

During finishing process of grade 2 titanium, the surface of the material is altered, and any imperfections or irregularities are removed. However, the presence of the alpha phase results in a visible grain structure on the surface, eventually leading to a grainy surface appearance, as shown below.

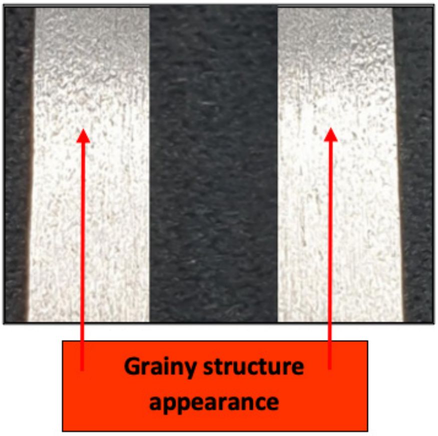

Figure 2: Ti Grade 2 Metal

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Microstructures of Grade 5 Titanium

Titanium Grade 5 (Ti-6Al-4V) has a more complex microstructure compared to Grade 2 titanium. It consists of a combination of alpha (α) and beta (β) phases. The presence of the beta phase, which is typically harder and has a finer grain structure, can contribute to a smoother surface appearance after finishing.

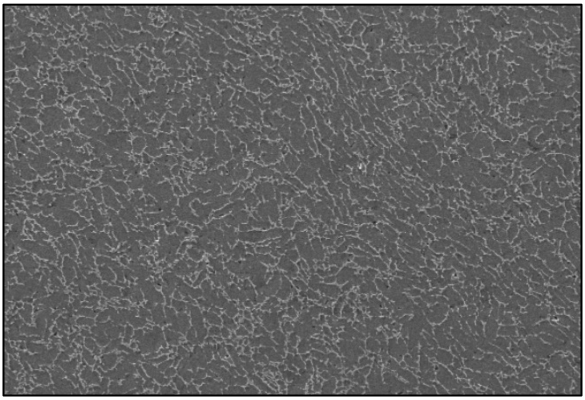


Figure 3: Microstructure of Titanium Grade 5

Based on above research Sunjewels conducted extensive evaluations across titanium grade 2 & grade 5. Titanium Grade 5 emerged as the material of choice due to its remarkable surface finishing capabilities. Titanium grade 5 exhibited superior surface refinement after the finishing processes that Grade 2 titanium couldn't sufficiently meet, its finishing stages resulted in a grainy appearance, falling short of the impeccable surface finish demanded by the customer. The below figure shows that surface pattern achieved by Sunjewels R&D expertise.

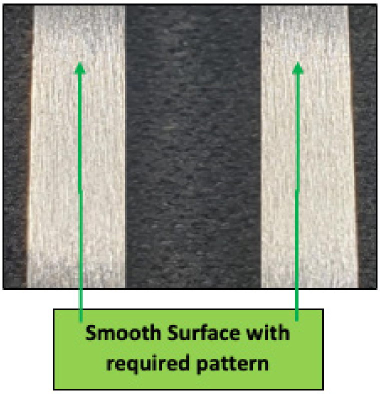


Figure 4: Ti Grade 5 Metal

Why Titanium Grade 5 is difficult to Machine?

Figure 5: Titanium Machining

The difficulty in machining titanium stems from a blend of its material characteristics and the complexities they introduce to the machining process. Here are the primary reasons for the challenges associated with machining titanium:

- **High Strength**: Titanium's exceptional strength-to-weight ratio, while advantageous for various applications, requires substantial force to cut and remove material during machining. This elevated strength leads to increased cutting forces and tool wear.

- **Low Thermal Conductivity**: Titanium's limited ability to dissipate heat efficiently concentrates the cutting-generated heat in a small area. This results in heightened temperatures at the tool-workpiece interface, causing tool wear, workpiece distortion, and subpar surface finish.

- **Chemical Reactivity**: At elevated temperatures, titanium reacts readily with oxygen, forming abrasive titanium oxide (TiO2) layers. These layers can detrimentally impact tool life and surface quality.

- **Work-Hardening**: Titanium undergoes rapid work-hardening when machined, increasing its hardness during deformation. This characteristic elevates the machining challenge and accelerates tool wear.

- **Low Elastic Modulus**: Titanium's low elastic modulus induces significant elastic deformation, causing spring-back and reduced dimensional accuracy in machining processes.

- **Abrasive Properties**: Titanium exhibits abrasive tendencies toward cutting tools, causing rapid tool wear. Furthermore, the abrasive nature of titanium chips contributes to built-up edge (BUE) formation on the cutting tool.

- **Challenging Chip Control**: Effective chip control is critical in titanium machining. Poor chip control can result in chip welding, where chips adhere to the tool, causing tool breakage and inferior surface finishing.

Introduction to CNC Machine

In 2018, Sunjewels made a strategic investment in the 5 axis CNC, a CNC machine renowned for its precision and versatility in dental manufacturing. This acquisition marked a pivotal step forward for Sunjewels, positioning the company at the forefront of technology-driven production before the onset of the global pandemic. The 5 axis CNC boasted cutting-edge features, including high-speed milling capabilities, multi-axis functionality, and advanced CAD/CAM integration, empowering Sunjewels to craft intricate and precise designs.

Sunjewels witnessed a significant leap in their product development initiatives with the integration of titanium projects into their machining repertoire, utilizing the cutting-edge capabilities of the Coritec machine. The introduction of titanium machining marked a pivotal expansion in their materials portfolio, reflecting their commitment to innovation and diversification.

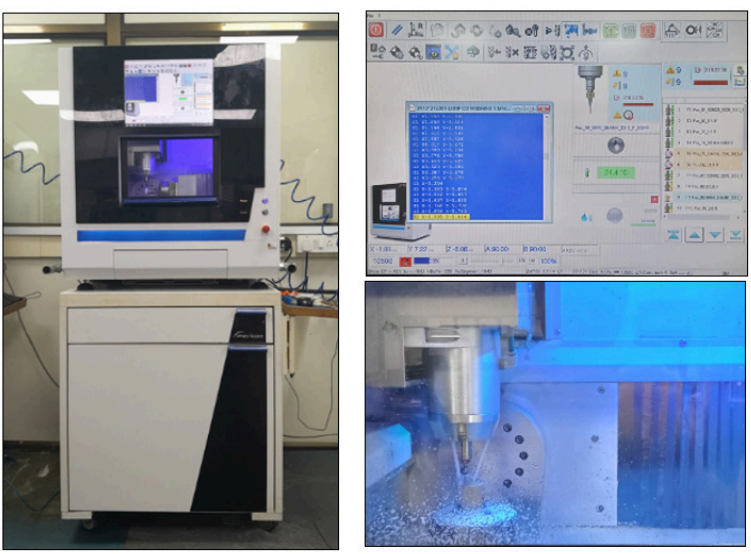


Figure 6: 5 Axis CNC Machine

Challenges faced during Titanium Machining:
During the titanium product development phase on the CNC machine, Sunjewels encountered several challenges inherent to working with this demanding material, they are as follow:

- Titanium's hardness and toughness posed machining difficulties, leading to increased tool wear and reduced machining speeds. Due to this, cycle time was very high.
- The material's tendency to generate heat during cutting required precise cooling and lubrication strategies to prevent thermal deformation and maintain machining accuracy.
- Achieving intricate designs in titanium demanded meticulous programming and tool path optimization to mitigate vibration and ensure precision.
- In machining of Ti material, due to high-spindle speed, tools, incorrect cutting parameters, leads to the ignition of titanium particles or chips which is a safety hazard concern.

Figure 7: CNC Machining Incident - Fire Occurrence

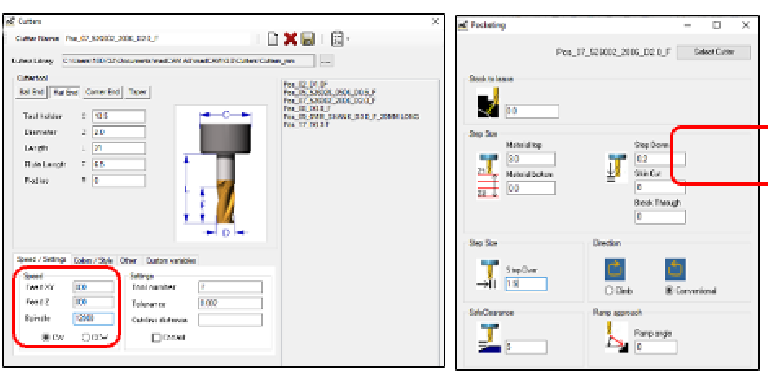


Figure 8: CNC Programming Screen with current parameters

Table 2: Current Parameters

Tool	Feed (XY) mm	Feed (Z) mm	Spindle Speed (RPM)	Step Down (mm)
2mm Flat End Mill	800	800	12000	0.2

The current CNC machine parameters lead to ignition during titanium machining. To avoid this hazard conditions, we did WHY-WHY analysis to find the root causes.

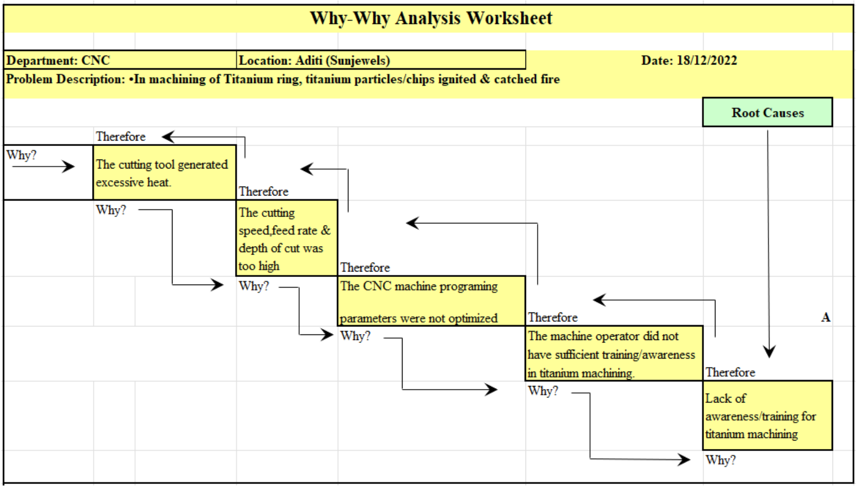


Figure 9: WHY-WHY Analysis

To address the challenges encountered in machining of titanium, Sunjewels adopted a proactive approach around studying titanium grade 5 metal and optimizing both tooling and CNC machine parameter.

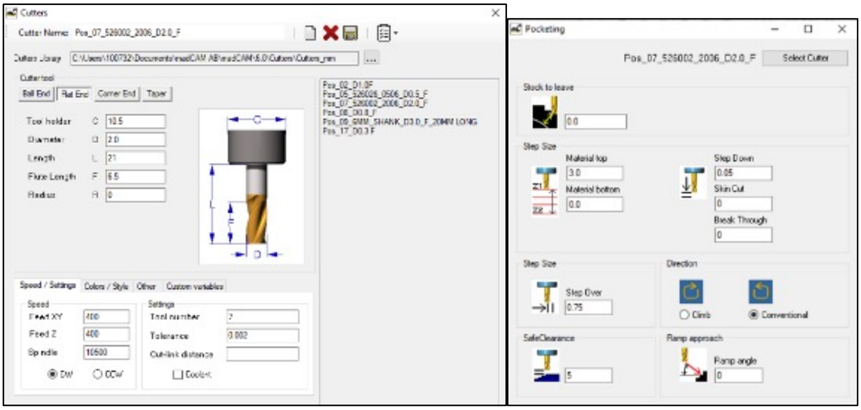


Figure 10: CNC Programming Screen with modified parameters

Table 3: Modified Parameters

Tool	Feed (XY) mm	Feed (Z) mm	Spindle Speed (RPM)	Step Down (mm)
2mm Flat End Mill	400	400	10500	0.05

Tool Selection for Titanium Machining:

- Flute Length
- Helix Angle
- Positive Rake Angle
- Grades with coating: PVD, DLC, TiAIN, TiCN etc

Flute Length:

When machining titanium with carbide flat end mills, it's generally recommended to use end mills with longer flute lengths to accommodate deeper cuts and to ensure efficient chip evacuation. For machining titanium, end mills with flute lengths typically ranging from 1.5 to 3 times the diameter of the end mill is commonly used.

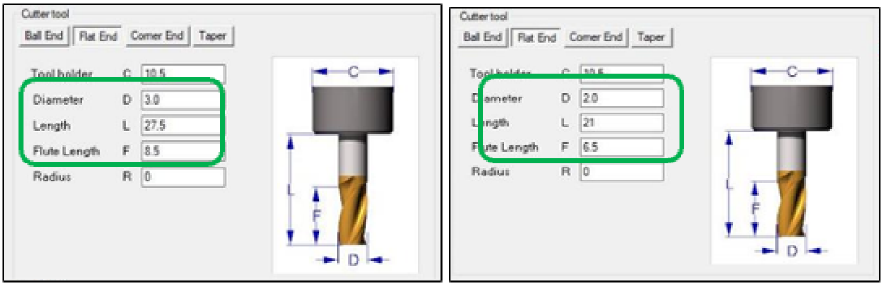


Figure 11: Tool Diameter & Flute Length

High Helix Angle:
Helix angles in the range of 30 to 45 degrees are commonly recommended for optimal performance when machining titanium. In below image, the helix angle 3mm flat end mill is 43.107°.

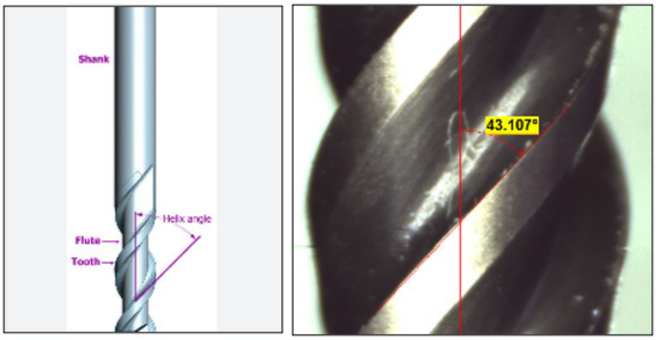


Figure 12: Helix Angle

Positive Rake Angle:
When cutting titanium with flat end mills, a positive rake angle is typically preferred. A positive rake angle helps to reduce cutting forces and improve chip evacuation, which is crucial for machining titanium effectively. The recommended rake angle for flat end mills when cutting titanium is generally between 5 to 15 degrees positive. In below image rake angle is 13.184°

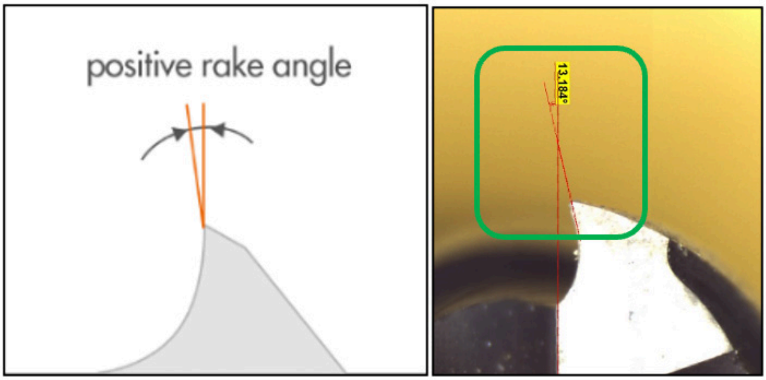


Figure 13: Positive Rake Angle

Grades of Carbide used in tools:
Carbide end mills are available in various grades, each designed for specific materials, cutting conditions, and applications:

- **KMG303**: PVD coated carbide substrate for universal milling application of steel (up to HRC<=48), stainless steel and cast iron. This grade is often suitable for general-purpose milling applications. It offers good wear resistance and toughness, making it versatile for machining various materials, including steels, stainless steels, titanium and cast iron.
- **KMG405**: PVD coated carbide substrate for high performance milling application of steel (up to HRC <55), stainless steel, super alloy material and cast iron. It is known for its excellent wear resistance and high-temperature resistance, KMG405 is a grade suitable for machining hardened steels, high-temperature alloys, and materials that demand higher cutting speeds. It's designed to withstand higher cutting temperatures without compromising on tool life.
- In the machining of Ti composite materials, stringent safety protocols, including controlled machining speeds i.e. spindle speed & reduction in depth of cut were adopted to mitigate the risk of ignition, ensuring a safe and secure machining environment without compromising efficiency or quality.

Features of Carbide Tools:

- Optimized geometry improves chip removal and chip forming with reduced cutting force.
- Higher feed rates and improved metal removal rates for efficient machining, due to high stability of cutting edge and rigid tool structure.
- With excellent wear resistance and toughness, high wear resistance and breakage resistance is achieved even during high performance milling.

TOOL LIFE MONITORING

Tool life monitoring during titanium machining stands as a critical facet in Sunjewels precision-driven approach. Recognizing the inherent challenges posed by machining titanium, particularly it's high strength, low thermal conductivity, and abrasiveness.

This proactive approach not only ensures consistent and high-quality machining but also aids in refining machining processes for enhanced efficiency and cost-effectiveness. Sunjewels commitment to leveraging technology for precise tool management underscores their dedication to delivering top-tier products while maintaining an edge in the competitive landscape of precision machining.

Titanium Jewellery Manufacturing Challenges post CNC Machining:

Titanium has gained popularity in the jewellery industry due to its unique properties, but there are challenges associated with working with this metal for jewellery making. Here are a couple of scenarios that illustrate challenges and solutions in titanium product development:

Case Study

Porosity & Orange peel effect after manual polishing process:
Porosity and the orange peel effect can sometimes emerge as challenges following the manual polishing process of titanium rings. Despite the meticulous handcrafting involved, certain imperfections like porosity, visible as tiny air pockets or voids on the ring's surface, might occur. Additionally, the "orange peel" effect develop due to inconsistencies in the polishing process. These occurrences, though unwelcome, can be inherent to manual polishing methods, especially when dealing with titanium, a material known for its sensitivity to polishing techniques. Addressing these issues often requires a delicate balance between refining polishing methods and ensuring the preservation of the ring's structural integrity and design aesthetics.

Process Followed –

- Finishing by paper with a high grit count
- Manual Finishing by felt pad (Black compound)
- light buff (Blue compound)

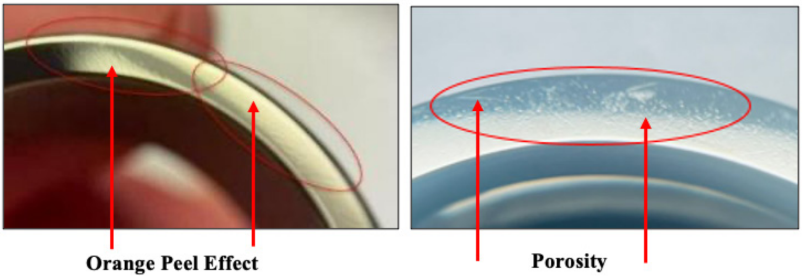


Figure 14: Ti Grade 5 orange peel effect & porosity

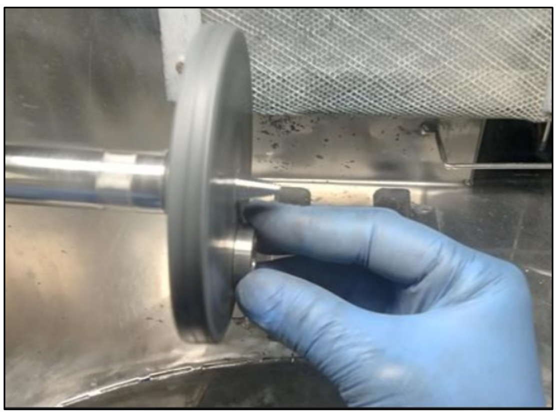


Figure 15: Manual Finishing by felt pad

To remove orange peel effect & porosity we introduced a lapping machine. The details are as follows:

Lapping Machine:
Lapping machine is basically a tabletop machine best to suit high degree of Flatness & Surface Finish. Employing a rotational motion, the lapping machine ensures an even distribution of the abrasive mixture, gradually removing material from the workpiece surface. The principle behind a lapping machine revolves around the controlled abrasion of surfaces to achieve precise flatness, smoothness, and tight tolerances.

Working Principle:
- Lap/polish plates revolves at low RPM.
- The conditioning rings located in position on the machine plate also rotate freely.
- The work pieces are kept freely inside conditioning rings with the surface to be lapped mating the Lap Plate.

- The sharp abrasive particles which are continuously fed on the machine plate get impregnated in the Lap plate and cut the material from the surface of the work piece and creates replica of the plate's flatness on to the same.

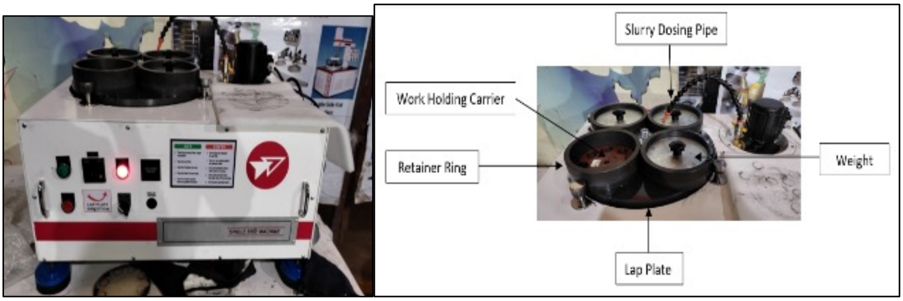
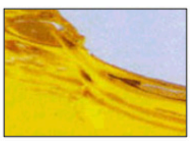


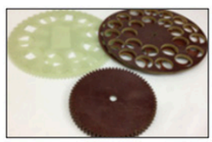
Figure 16: Lapping Machine

Consumables/Fixtures:

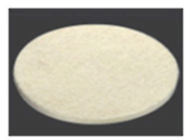
Aluminium Oxide Powder



Lapping Oil



Work Holding Carriers



Felt Pad

Diamond Paste

Moistening Spray

Figure 17: Lapping Machine Consumable

Process Re-engineered:

- Lapping by machine
- Light finishing by felt pad using white compound.
- Ligh buffing by using blue compound.

Figure 18: High polished Ti Ring

B) No uniform matt finish pattern on Ring surface:
The absence of a uniform matte finish pattern on a ring surface can stem from various factors during the finishing process. Achieving a consistent matte finish across the entire surface of a ring involves meticulous attention to detail and precision. Deviations in the finish can occur due to inconsistencies in polishing techniques, variations in pressure applied during the finishing process, or differences in the composition of the ring material. Factors such as the presence of impurities or irregularities in the metal, variations in the polishing tool or technique used, or even the skill level of the craftsman performing the finishing can contribute to the lack of uniformity in the matte finish. Addressing these inconsistencies often requires refining the polishing methods, adjusting pressures, or employing more standardized techniques to ensure a consistent and even matte finish throughout the ring surface.

Process Followed:
- Manual matt finishing using paper with high & low grit count.

Figure 19: Manual Matt Finishing

To get uniform matt finish pattern on ring surface we introduce desktop robot & the details are as follows:

Figure 20: Desktop Robot

The desktop robot is an ultra-compact robotic arm with footprint smaller than a piece of A4 size paper. It is safe for human collaboration, easy to use, and quick to deploy, making it perfect to automate small batch flexible productions.

The desktop robot represents a cutting-edge addition to the realm of robotic automation, boasting a blend of versatility, precision, and efficiency. This robotic arm, equipped with state-of-the-art technology, offers a wide range of functionalities, catering to various industries and applications. With its robust build and high payload capacity, the desktop robot executes tasks with exceptional accuracy and repeatability. The desktop robot stands as a testament to the advancements in robotics, providing a reliable and adaptable solution for businesses seeking streamlined automation and enhanced productivity.

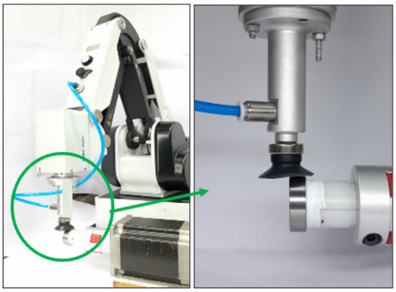


Figure 21: Matt finish by Desktop Robot

Creating a matte finish through a desktop robot involves meticulous control and precision. The process typically begins with the selection of appropriate tools and techniques compatible with the robot's capabilities. The robot's articulated arm allows for controlled movements and application of specific abrasives or finishing materials onto the surface, ensuring uniformity in the finishing process. By manipulating the robot's movements and adjusting parameters like pressure and speed, a consistent matte finish can be achieved across various surfaces. This method offers a level of accuracy that's hard to attain manually, allowing for intricate detailing and the attainment of desired surface textures with efficiency and reproducibility.

Sunjewels has carved a niche for itself in the realm of matte finishing, showcasing an exceptional mastery in this artistry, especially through the adept use of desktop robots. Sunjewel's expertise lies in leveraging the precision and control offered by these robots to achieve immaculate matte finishes across various surfaces. This precision-driven approach results in an impeccable matte finish that exudes uniformity and finesse, elevating Sunjewels reputation as a leader in achieving top-tier surface textures through innovative and technologically advanced methodologies.

Process Re-engineered:

- First matt finish effect using paper with high grit count mounting on lathe machine.
- Final matt finish effect using paper with low grit count mounting on robot.

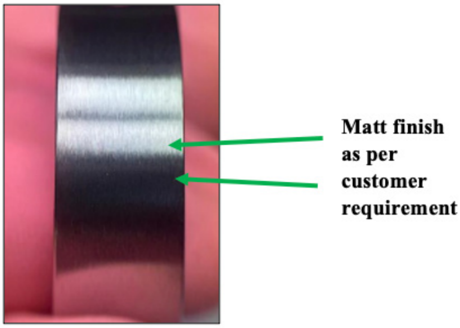


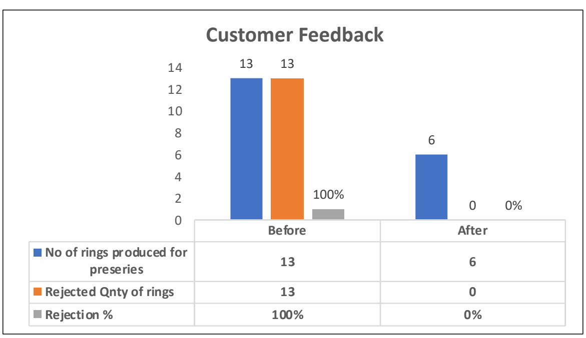
Figure 22: Matt finishing/texturing by Desktop Robot

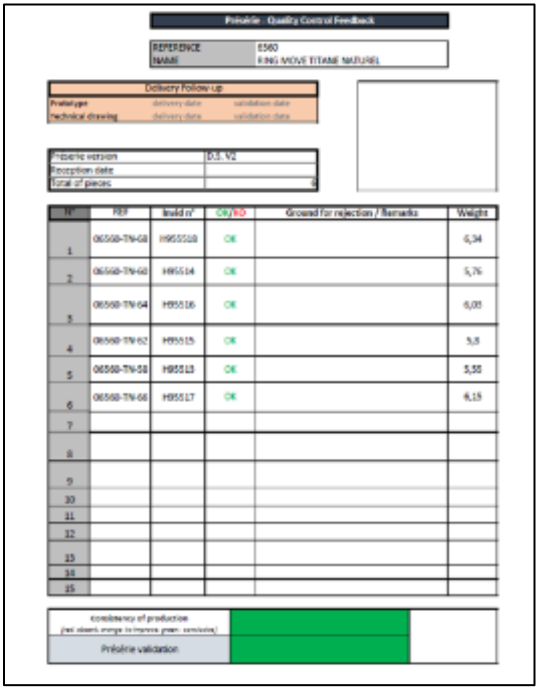
Customer Delight:

Customer's satisfaction following the resolution of challenges in the pre-serie phase of our titanium products is a testament to our commitment to excellence and customer-centricity. The successful mitigation of issues has not only revitalized customer's confidence in our products but has also reinforced the trust they place in our brand. Through dedicated problem-solving and refinement of processes, we've not only met but exceeded customer's expectations, leading to a noticeable upsurge in their satisfaction levels.

The positive impact of our efforts is reflected in the feedback received from customer, highlighting their appreciation for our responsiveness, dedication, and the improved quality of our titanium products. This heightened satisfaction has translated into increased confidence in placing repeat orders and a strengthened partnership between us and customer.

By addressing challenges early on in the pre-serie lot, we've not only improved the quality of our titanium products but also streamlined our processes, ensuring smoother interactions and better service for customer. This success story with customer is a testament to our ability to listen, adapt, and evolve, ultimately fostering a more robust and enduring relationship with them.
Moving forward, we remain committed to upholding this standard of excellence and ensuring that all our valued customers continue to experience the highest levels of satisfaction and trust in our titanium product line. Their satisfaction stands as a beacon guiding our ongoing commitment to quality and customer service.





Présérie - Quality Control Feedback

REFERENCE	6560
NAME	RING MOVE TITANE NATUREL

Delivery Follow up		
Prototype	delivery date	validation date
technical drawing	delivery date	validation date

Présérie version	D.S. V2
Reception date	
Total of pieces	6

N°	REF	Invoice n°	OK/KO	Ground for rejection / Remarks	Weight
1	06560-TN-68	H955518	OK		6,34
2	06560-TN-60	H95514	OK		5,76
3	06560-TN-64	H95516	OK		6,03
4	06560-TN-62	H95515	OK		5,8
5	06560-TN-58	H95513	OK		5,58
6	06560-TN-66	H95517	OK		6,15
7					
8					
9					
10					
11					
12					
13					
14					
15					

consistency of production		
Présérie validation		

Figure 23: Customer QC Feedback

Titanium Triumph: Surge in Production Orders

Following the successful resolution of pre-series challenges in their titanium products, Sunjewels has experienced a substantial upsurge in customer orders. This overwhelming response has prompted the company to make strategic decisions to expand its machining capacity significantly. Among the key initiatives is the introduction of a high end 5-axis CNC machine, poised to elevate their manufacturing capabilities to a whole new level.

The rectification of issues encountered during the pre-series phase has proven to be a turning point for Sunjewels. With a refined product line and enhanced quality standards, customer confidence has soared, reflecting in a notable increase in orders. The company's commitment to addressing any teething issues early on has not only bolstered customer trust but has also positioned Sunjewels as a reliable and responsive partner in delivering top-tier titanium products.

In response to this surge in demand, Sunjewels is proactively investing in its production infrastructure. The addition of a high-end 5-axis CNC machine stands as a testament to their dedication to meeting and exceeding customer expectations. This advanced machining equipment promises precision, efficiency, and expanded capabilities in crafting intricate and high-quality titanium components.

The decision to expand machining capacity and integrate cutting-edge technology underscores Sunjewels commitment to continuous improvement and innovation. This strategic move not only addresses the current surge in demand but also positions the company for sustained growth and competitiveness in the ever-evolving market for titanium products.

The introduction of the high end 5-axis CNC machine represents a significant milestone for Sunjewels, marking a new chapter in their journey towards manufacturing excellence. As they gear up to expand their operations, Sunjewels reaffirms its dedication to delivering unparalleled quality and service while catering to the increasing needs of their valued customers in the realm of titanium products.

Machine Selection Criteria for Titanium Metal Machining
Choosing the appropriate CNC machine to work with titanium involves evaluating various essential factors and specifications to ensure its capability in handling the complexities of this challenging material.

- **Spindle Power**: Machining titanium necessitates substantial spindle power to manage its hardness and abrasive nature effectively.
- **Spindle Speed**: Efficient titanium machining often demands high spindle speeds to maintain optimal cutting rates. Opt for a machine with a maximum spindle speed surpassing 10,000 RPM for better performance.
- **Machine Type**: Determine whether a Vertical Machining Centre (VMC) or Horizontal Machining Centre (HMC) suits the specific titanium components based on their size and intricacy.
- **Machine Rigidity**: Given the significant cutting forces involved in machining titanium parts, ensuring the machine's rigidity and stability is crucial to minimize vibrations and deflection during operations. A stable machine enhances surface finish and prolongs tool life.
- **Tooling**: Specialized cutting tools like carbide or high-speed steel with specific coatings (e.g., TiAlN) are necessary for titanium machining to endure the high temperatures generated during cutting.
- **Cutting Tool Cooling**: Efficient cooling systems are critical to dissipate heat and prevent tool wear. Machines equipped with high-pressure coolant systems facilitate effective chip evacuation and cooling in the cutting area.
- **Control System**: Select a CNC machine equipped with an

advanced control system that supports high-speed machining and adaptive toolpath generation. This aids in optimizing the cutting process and reducing machining duration.

- **Work Holding**: The work holding system should securely grip the titanium workpiece, ensuring stability and preventing vibration or movement during machining."

High End 5-Axis Vertical Machining Centre:

Due to the surging demand for titanium-based products, the need for advanced coolant features, and the pursuit of higher machining speeds, Sunjewels made a strategic move by introducing High End 5-axis Vertical Machining Centre (VMC) into their manufacturing facility.

Figure 24: High End 5 Axis

In the high-volume production industry, the task of achieving the requirements of customers such as shorter turnaround, higher quality and lower cost has become a constant challenge for the machine tool designer. The high end VMC is well known for bringing quality and reliability through its innovative machining centres, technologies, and process know-how. Sunjewels new compact Vertical Machining Centre provides high performance and extremely efficient machining for high volume part production. The new VMC is ideally suited for a wide array of component machining applications focused on maximizing machining process, increasing flexibility, achieving smooth workflow and various types of automation. The High end VMC adopts fixed table design to provide customer flexibility for fixture design to meet demands of larger envelope, higher fixture weight and simple interfacing that allows a wide range of machining applications. Finite Element Analysis (FEA) design techniques were employed to optimize structural rigidity and torsional stiffness for ultimate performance and consistent results. The machine structural configuration is based on a closed frame type design together with a pair of long supporting columns achieving superior structural rigidity.

The Spindle rigidity, higher speed, constant pre-load, multi-plane balancing, minimum vibration and reduced thermal growth are key topics that machine has pioneered through the art of spindle making by innovative design and manufacturing. The VMC comes with 2 spindle specifications to cater to the varying machining applications for high volume production machinery industry demands.

Created for the production environment, the machine coolant system enhances the productivity. Configured with nozzle and flush coolant as standard features, chips are efficiently removed from the cutting zone. The structure of machine is designed with a slope for quicker evacuation. A Lift up chip Conveyor can be integrated at the rear of the machine to tailor to high chip generation demands.

5 Axis CNC and High End VMC Comparison

5 axis CNC machines and high-end Vertical Machining Centres (VMCs) stand at contrasting ends of the CNC machining spectrum, each offering distinct advantages. Here are a few important specifications for comparison:

Specification	Existing 5 Axis CNC	High End VMC
Spindle Power	The existing machine is generally used for dental applications and has low spindle power <1kw	This machine has high Spindle power >7kw and has high traverse feed rates. Basically, used for cutting high hardened materials like Titanium and HSS.
Spindle Speed	Variable spindle speeds designed for efficient cutting rates, but specific details might vary based on the model and configuration.	Offers variable spindle speeds, often optimized for high-speed machining, providing efficient cutting rates.
Coolant Type	Utilizes coolant systems for chip evacuation and cooling during machining operations, though specific types may vary based on machine specifications. Flow rate – 3 - 4 LPM.	Utilizes high-pressure flooded coolant systems to ensure efficient chip evacuation and cooling during machining operations. Flow rate - 150 LPM.
Precision	Suitable for a wide range of applications but might have slight variations compared to high-end machines.	Suitable for intricate and fine-tolerance machining tasks.
Machine Rigidity	Rigidity might vary depending on the specific model and build, but typically designed to offer stable machining operations.	Machines are typically built with a focus on rigidity and stability to minimize vibrations and deflection during cutting operations, contributing to better surface finishes and longer tool life.
Cost	Often position themselves in the market as cost-effective solutions, aiming to provide quality performance at a more accessible price point.	Often positioned at a higher price point in the market due to their advanced capabilities and engineering.

Stone Setting in Titanium:
Setting stones in titanium jewellery is a precise and delicate process that requires skill and attention to detail. Titanium is a popular choice for jewellery due to its durability, lightweight nature, and hypoallergenic properties. When discussing the differences between stone setting in titanium compared to other precious metals, several key points can be covered:

- **Hardness and Strength**: Titanium is significantly harder and stronger than traditional precious metals like gold or silver. This difference in hardness affects the ease of manipulation and requires specialized tools like carbide and techniques for stone setting.
- **Malleability**: Precious metals are more malleable and ductile than titanium, allowing for easier manipulation and adjustment during stone setting. Titanium's stiffness necessitates greater precision and care during the setting process.
- **Brittleness**: The brittleness of titanium makes it more prone to fracture or cracking if excessive force is applied during the pre-cutting process, particularly when forming or manipulating prongs.

Tools for Stone Setting in Titanium:
Stone setting in jewellery making requires several specialized tools to ensure precision and security. Some of the essential tools used in stone setting include:

- **Grain Tool**: Grain tool helps create the tiny metal beads or grains that are used in settings to secure gemstones in place. The grain tool typically consists of a handle with a small, precise tip that can be used to shape and manipulate metal wire into tiny beads or prongs.

Figure 25: Grain Tool

- **Knife Graver**: A knife graver is a specialized tool used in stone setting for cutting or engraving metal. A knife graver is often used by jewelers to create seats or notches in metal to precisely hold gemstones.

Figure 26: Knife Graver

• **Flat Graver**: This has a flat cutting edge, is particularly useful for various tasks related to metal engraving and shaping such as Preparing Metal Surfaces, Creating Seats for Stones, Detailing and Finishing.

Figure 27: Flat Graver

• **Round Bur**: A round burr is a rotary tool attachment used to create rounded cavities or seats in metal settings for gemstones. It's a cylindrical-shaped cutting tool with a rounded end, available in various sizes corresponding to the dimensions of the stones being set.

Figure 28: Round Bur

• **Cross Bur**: A cross burr is a specialized rotary tool attachment used in jewellery making and metalwork. It has a unique shape that resembles a cross or X when viewed from the end, with cutting edges at each end of the cross. This tool is designed to create precise, cross-shaped cuts or grooves in metal.

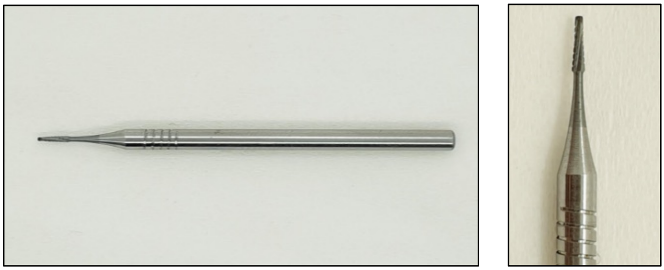


Figure 29: Cross Bur

- **Hart Burr**: This tool would likely be used for creating heart-shaped or curved designs in metalwork or jewellery. Jewellers use these tools to engrave or carve heart-shaped patterns or cavities in metal surfaces for decorative or setting purposes.

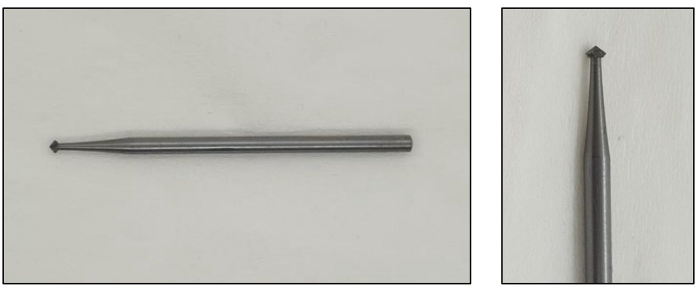


Figure 30: Hart Bur

- **Cup Burr**: A cup burr is a rotary tool attachment used in jewellery-making and metalworking. It has a cup-shaped cutting edge and is designed to create smooth, rounded edges or to deburr metal.

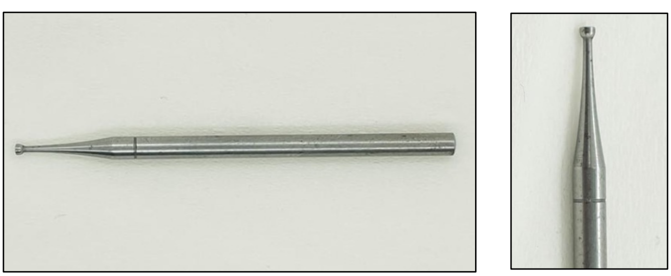


Figure 31: Cup Bur

HSS burs in Metal Setting:

High-speed steel (HSS) is a special alloy steel that's made by combining steel with Tungsten, Chromium, Vanadium, Cobalt, Molyb-

denum.
High-Speed Steel (HSS) is a type of steel known for its excellent properties that make it well-suited for cutting tools, including burs used in various industries, including metalworking, woodworking, and jewellery making. Here are some key material properties of High-Speed Steel burs.

- **Hardness**: HSS burs exhibit high hardness, though not as high as materials like tungsten carbide. The typical hardness of HSS falls in the range of 60 to 70 HRC (Rockwell hardness scale). This hardness enables them to retain their cutting edge when used for cutting, drilling, or shaping materials.
- **Toughness**: HSS possesses a good balance of hardness and toughness. This property makes it less brittle compared to some other hard materials, allowing HSS burs to withstand impacts and shock during cutting processes without fracturing easily.
- **Wear Resistance**: While not as wear resistant as tungsten carbide, HSS burs still have good wear resistance, particularly when used within their recommended operating parameters. They can maintain their cutting edges for a reasonable amount of time before requiring sharpening.
- **Heat Resistance:** HSS has excellent heat resistance, enabling it to withstand high temperatures generated during cutting processes. This property helps prevent deformation of the cutting edge at elevated temperatures.
- **Machinability**: HSS is relatively easy to machine and grind, allowing for the production of intricate cutting tool designs and shapes. This feature makes it convenient for customizing burs for specific applications or designs.
- **Versatility**: HSS burs are versatile and can be used on various materials, including metals, plastics, and wood. They are suitable for applications where a balance of cutting performance, durability, and cost-effectiveness is required.

Stone Setting in Titanium Ring:

Stone setting in a titanium ring combines the strength and durability of titanium with the timeless elegance of diamonds, resulting in a unique and eye-catching piece of jewellery. Here's a detailed look at the process:

- **Seat Creation:**

Make the seats for the diamonds first. Cut tiny, accurate indentations or seats into the titanium surface with round bur. The diamonds will be held firmly in place and correctly aligned by these seats.

Figure 32: Seat Creation

- **Groove for setting:**

Groove refers to the metal portion that will secure the diamonds in place. Make the groove by carefully shaping and forming the metal around the seats. This involves precise metalwork to create the structure that will hold the diamonds securely.

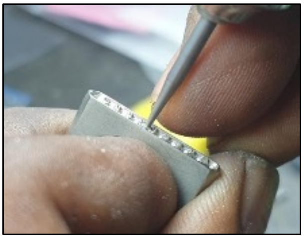


Figure 33: Groove for setting

- **Prong Splitting:**

For a prong setting, split the metal into individual prongs. The number of prongs will depend on the design and style. Typically, a four-prong or six-prong setting is common for holding round diamonds. Ensure that the prongs are evenly spaced around each seat.

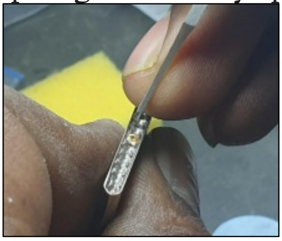


Figure 34: Prong Splitting

- **Prong Pressing:**

With the diamonds in place, carefully press and secure the prongs over each diamond. This involves using controlled pressure to ensure that the prongs hug the diamonds securely without causing any damage. The prongs should be shaped and finished neatly for a polished look.

Figure 35: Prong Pressing

Output:

*Figure 36: Final Product after polish*ing

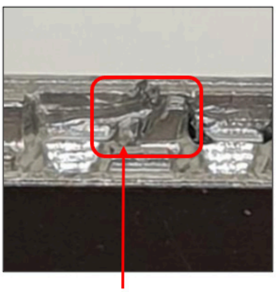
Based on above experiences team has developed different designs Titanium jewellery,

Figure 37: Titanium jewellery

Challenges in stone setting:
Given titanium's hardness and brittleness, one of the major challenges faced while stone setting in titanium is the risk of cracking or fracturing the material during the setting process.

Case Study:

- In pre-cutting process, while splitting the prongs got cracked.
- Upon closer examination, it is determined that the cracking of the prong during pre-cutting is primarily attributed to the inherent brittleness of titanium and the use of conventional cutting tools designed for softer metals. The excessive strokes and pressure applied during the cutting process exceeds the material's capacity to deform plastically, resulting in localized stress concentrations and subsequent cracking of the prongs.
- Parameters of graver smith equipment which were set during pre-cutting are as follow,



Prong breaks during precutting process

Figure 38: Prong Breakage

Figure 39: Graver smith cur rent parameters (SPM & Pressure)

Table 4: Current Parameters

Parameter	Specification
Strokes Speed	3300 SPM
Pressure	40 psi

Process Re-engineered:

Upon closer examination & several trials we arrived on below parameters.

Figure 40: Graver smith correct parameters (SPM & Pressure)

Table 5: Modified Parameters

Parameter	Specification
Strokes Speed	1400 SPM
Pressure	28 psi

Challenges with HSS burs:

- Titanium is known for its hardness and abrasiveness, which leads to accelerated wear and dulling of HSS burs.
- The high hardness of titanium, coupled with its poor thermal conductivity, can result in significant heat generation during manual setting with HSS burs. Excessive heat affects the integrity of both the metal and the diamonds, potentially leading to damage or deformation.
- Titanium is a challenging material to cut due to its toughness. HSS burs faces resistance and difficulty in penetrating the titanium, especially when intricate details or precise cuts are required.

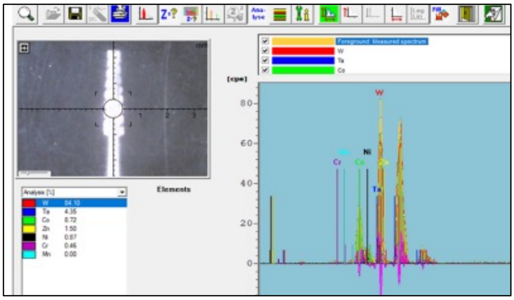
Carbide burs performance over HSS burs:

In the production or machining of titanium, carbide burs are generally preferred over High-Speed Steel (HSS) burs for below reasons:

- Titanium is a challenging material to machine due to its high strength and tendency to work-harden. Carbide burs, with their exceptional hardness and wear resistance, are better suited for cutting and shaping titanium. They maintain their cutting edge for a longer time compared to HSS, providing more consistent and effective cutting performance.
- Titanium has a relatively low thermal conductivity, which can lead to increased heat generation during machining. Carbide burs, being more heat resistant than HSS, can withstand the elevated temperatures encountered during titanium machining without losing their hardness and cutting edge.
- Titanium is abrasive and can cause rapid tool wear. Carbide burs, due to their hardness and wear resistance, endure this abrasive nature more effectively than HSS burs, resulting in less frequent tool changes and increased productivity.
- Carbide burs offer better precision and can maintain a con-

sistent surface finish when machining titanium. Their durability and ability to retain sharpness contribute to achieving finer details and smoother finishes on titanium workpieces.

- Carbide burs have a longer lifespan compared to HSS burs when machining titanium. Although carbide burs may have a higher initial cost, their durability and longer tool life result in reduced overall tooling costs over time.



Carbide Bur Composition (%)	
Tungsten	84.10
Tantalum	4.35
Cobalt	8.72
Zinc	1.5
Nickel	0.87
Chromium	0.46

Figure 41: Carbide Bur XRF Report

Casting of Titanium Product:

Casting titanium involves a process that can be quite complex due to titanium's properties, particularly its high reactivity and melting point.

The casting of titanium stands as an exemplary process showcasing precision and innovation. Leveraging cutting-edge technology and a commitment to excellence, the company's titanium casting process begins with the meticulous selection of high-quality commercially pure titanium. Employing state-of-the-art melting equipment capable of withstanding extreme temperatures, the titanium is carefully melted in a controlled environment, ensuring purity, and preventing oxidation. Sunjewels dedication to quality extends to the casting moulds, crafted from specialized refractory materials, meticulously prepared to endure the intense heat required for casting. Under stringent quality controls and utilizing vacuum or inert gas atmospheres, the molten titanium is poured into these Molds, guaranteeing the integrity of the final product. Post-casting, meticulous attention is devoted to additional processes, including heat treatment and precision machining, ensuring each titanium piece embodies the desired structural integrity, surface finish, and exacting specifications synonymous with Sunjewels commitment to excellence.

The Titanium Casting Machine stands as the pinnacle of advanced technology and precision in the casting process. The casting machine is equipped with cutting-edge features designed specifically for titanium casting, showcasing unparalleled temperature control and a vacuum or inert gas environment, safeguarding the titanium's purity and integrity during the melting process. Its robust construction and sophisticated controls ensure precise pouring into meticulously prepared Molds, maintaining the exacting standards of Sunjewels craftsmanship. The machine's capabilities, coupled with Sunjewels expertise and commitment to quality, guarantee the production of high-quality titanium components with exceptional structural integrity, superior surface finish, and adherence to the most stringent specifications.

Technical Specifications	
Variable Power	Min 50 Amp Max 250 Amp
Maximum current phase consumption	17 Ampere
Duration cycle fusion	150 Sec
Maximum amount per melting	Titanium - 40 g
Minimum pressure protection gas	4 Bar
Inert-gas consumption per melting/casting cycle	8 litres at 4 bars
Air compressor	Min 6.5 bar
Casting machine size (H x L x P)	76 x 34 x 65 cm
Empty weight of casting machine	40 Kg

Figure 42: Titanium Casting Machine

Casting Process:

1. **Wax Injection in mould & Tree Making**: The art of wax injection into moulds is a meticulous and precise process, showcasing the pinnacle of craftsmanship and innovation. Using wax injection machinery each step is methodically executed to perfection. This precise stage sets the foundation for crafting flawless replicas of intricate jewellery pieces or components. Highly skilled artisans meticulously assemble individual wax patterns onto a central wax sprue, creating intricate "wax trees."

Figure 43: Wax

Figure 44: Wax Tree

2. **Investment Preparation**: the preparation of investments for casting represents a meticulous and crucial stage in the production process.

Following are the materials required for investment preparation.

Table 7: Investment Preparation

Titec Investment Powder	Media
1 Kg	200 ml

Figure 45: Investment Powder & Media

Figure 46: Investment Flask

3. **Burnout Cycle**: the Burnout Cycle is one of the important phases during casting process. Once the investments are prepared, the burnout cycle meticulously removes the wax from the moulds, leaving behind precise cavities to be filled with molten metal. The investment is kept in the furnace for 10.5 hrs.

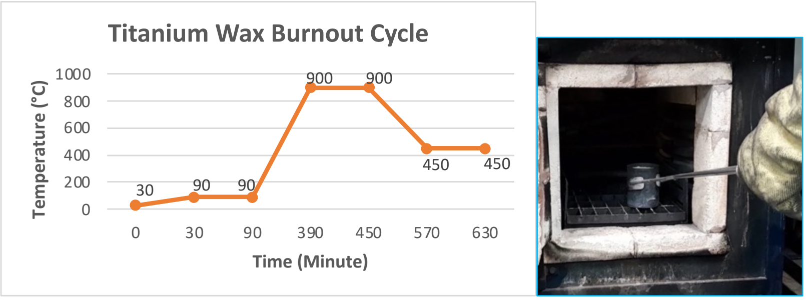


Figure 47: Burnout Cycle

4. **Casting**: molten metal is carefully poured into flasks, ensuring the faithful replication of intricate designs. Titanium Ingots are used to process castings.

Casting Ingot – ø 28mm

Copper Crucible - ø 42mm

Figure 48: Ti Casting Ingot & Crucible

The cycle begins with the creation of the vacuum inside the melting chamber (about 45 sec)
Followed by the introduction of Argon gas for about 20 seconds.
At the end of this phase the voltaic arc is triggered which ionizes the gas inside the melting chamber and allows the passage of the current necessary to the melting.
At the end of this phase the voltaic arc is triggered which ionizes the gas inside the melting chamber and allows the passage of the current necessary to the melting.
The melting/casting is made very fast: the whole cycle (vacuum, melting, casting and cooling down in Argon-gas) takes less than 3 minutes.

Air Pressure (Bar)	Argon Gas Pressure (Bar)	Casting Duration (Sec)
7	4	150

Table 8: Casting Parameters

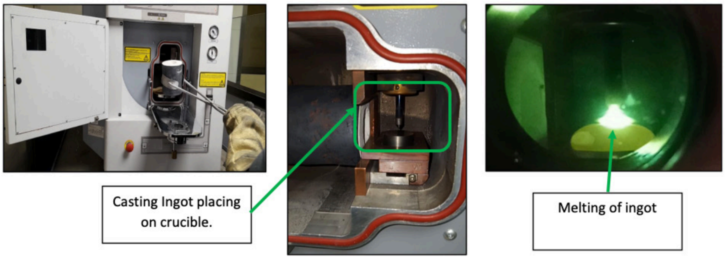


Figure 49: Ti Casting Process

Output:

Figure 50: Output of Ti Casting

Porosity in casting:

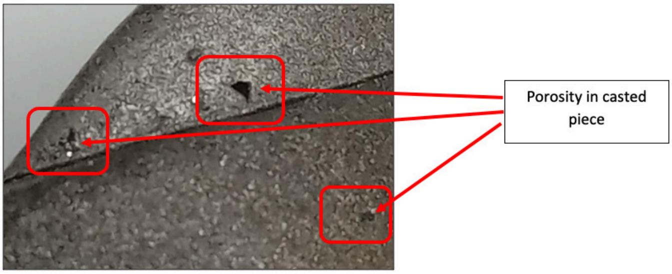


Figure 51: Porosity of Ti Casting

One common challenge encountered in titanium casted products is porosity. Porosity refers to the presence of voids or pores within the material, which can compromise mechanical properties and integrity. Below are the causes of porosity that are observed during casting,

• Air Entrapment: During investment preparation, if air bubbles are not fully evacuated, that will result in porosity in final output.

- Runners are inadequately placed, the flow of molten titanium alloy is hindered, resulting in uneven distribution within the mould cavity and inadequate venting of gases. Consequently, trapped air or gas pockets may not escape efficiently during solidification, creating voids or porosity within the casting.

Process Re-engineered:

- To enhance the casting quality of titanium components by increasing vibration in the machine during investment preparation while simultaneously creating a vacuum to evacuate air bubbles within the investment material. By subjecting the investment material to controlled vibrations, any trapped air bubbles are dislodged and brought to the surface, facilitating their removal.
- By altering the positioning of the runners within the wax tree, we aim to optimize the flow of molten titanium alloy during casting. This alteration can involve relocating the runners to better distribute the molten metal evenly throughout the mould cavity.

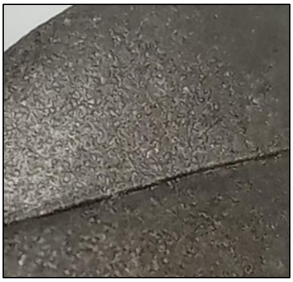


Figure 52: Final output (No Porosity)

Finishing & Polishing:

Electrolyte Polishing Machine:

DryLyte technology is a polishing system for metal components that achieves high performances and superior surface finishing. This technology was developed to overcome the limitations of classic electropolishing and mechanical processes and bring improvements to the processing of metal parts. The technology is based on cationic exchange made by diffusion between the solid bodies and metal surfaces. In comparison with liquid electropolishing technologies that aggressively attack the overall surface on independence of the roughness, Electrolyte technology only acts in micro peaks of roughness, thus respecting the shape and tolerances with few materials' removal.

Figure 53: Electrolyte Polishing Machine

Electrolyte Selection:
Selection of the electrolyte depend on the alloy of the sample to be polished. For Titanium based alloy group, the description of electrolyte is as follows:
DLYTE MIX MSA PLUS – S Ti 01: The Electrolyte is developed to treat a wide range of titanium alloys regardless the manufacturing method. It achieves a high brightness surface finishing.

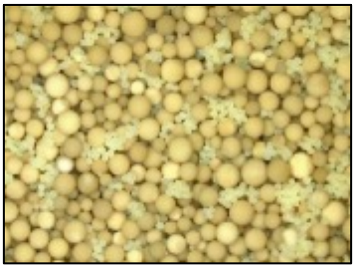
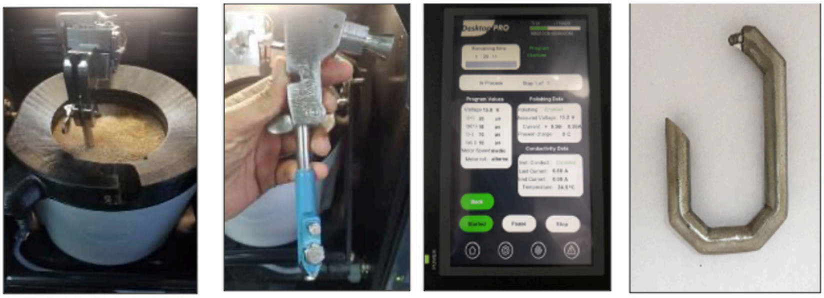


Figure 54: Electrolyte- DLYTE MIX MSA PLUS – S Ti 01

Process followed:



Mixer — Piece Holder — Program Window with Parameters — Input to machine

Figure 55: Machine parts, Programming window & input

Steps:

1. Piece holder is attached to mixer electrolyte conditioning is started for around 1 min till the instantaneous conductivity is 'Enabled' and electrolyte current is obtained. Add 100 ml DI water to the media if the media is dry and no current is obtained. During trials we obtained current = 0.88 A
2. Fix the piece in the holder and then run the program for 60 mins and then observe the output. Check the polishing quality of the product and if the piece is not polished again run the cycle for 30 mins to obtain better results.

Process Parameters:

Table 9: Process Parameters for finishing

Current (A)	Voltage (V)	T+	Tp +	T-	Tp -	Speed
0.88	15	20 µs	10 µs	70 µs	10 µs	Medium

Output:

Figure 56: Output of Polishing Machine

Customers Appreciation:

Sunjewels' acclaim was attributed to the genuine appreciation received from valued customers:

Testimonials of Elegance: Customers praised Sunjewels Titanium jewellery for its exquisite designs and superior craftsmanship. The pieces became expressions of individual style and garnered admiration for their uniqueness. Please refer below testimonial:

VERSION	SKU	NAME	TOTAL PIECES	CONSISTENCY OF PRODUCTION	DECISION	REMARKS/EXPECTATIONS	GO PRODUCTION/OTHER PRESERIE
V.2	6560	TITANIUM RING	6	*Conclusive*	*Validated*		OK
The preserie is validated, this is a very good job!							

Summary:
Sunjewel's has embarked on an innovative journey into the realm of titanium jewellery manufacturing, guided by a steadfast commitment to customer satisfaction and continuous improvement. The experiences in this endeavour have been shaped by valuable customer evaluation and progress, driving the company to refine the processes and offerings to exceed customer expectations. Following are the key points to note from the experiences:

- Pioneering Titanium Jewellery
- Customer-Centric Design Approach
- Continuous Improvement Through Customer Evaluation
- Enhancing Quality and Craftsmanship
- Empowering Customer Engagement

Conclusion:
Sunjewel's experiences in making titanium jewellery show the commitment to making great and innovative pieces by carefully picking top-quality titanium materials and use advanced methods to make the jewellery strong yet beautifully detailed. It adds special touches to the pieces with techniques like machine lapping and creating textured or matte finishes using a desktop robot. By embracing technology like high-end CNC machines, Sunjewels is leading the way in modern jewellery making. Overall, Sunjewels' manufacturing experiences in titanium jewellery showcase a commitment to pushing boundaries, delivering exceptional quality, and delighting customers with exquisite craftsmanship.

Way Forward:
The organization is on the verge of a dynamic future in titanium jewellery through a multifaceted approach that encompasses innovative designs, technology upgradation, and keen market research. The company recognizes the importance of setting itself apart through creative designs, investing in manufacturing setups such as CNC machines and collaborating with visionary customers to bring fresh perspectives to their titanium jewellery offerings. These aspects have not only enhanced the precision of their craftsmanship but also allows for greater customization, catering to individual tastes. Being attentive to market trends, Sunjewels conducts thorough market research to understand evolving consumer preferences. By coordinating their designs with modern trends, they ensure that their titanium jewellery remains not only technically advanced but also fashion-forward, meeting the demands of a dynamic and discerning market.

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