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Design for Manufacturing Assessment of Electric Scooter

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Content

Abstract

The competitive landscape of personal transportation is increasingly influenced by the efficiency of manufacturing processes and the practicality of product designs, particularly in electric scooters. This paper delves into the application of Design for Assembly (DFA) and Design for Manufacturing (DFM) methodologies to enhance the production of an electric scooter, focusing exclusively on its non-electronic components. The objective is to streamline manufacturing, reduce costs, and improve product durability without compromising performance.

DFA principles are implemented to simplify the assembly process of the electric scooter. The study begins with analysing the scooter's structure, and identifying ways to reduce the total number of parts, directly correlating with decreased assembly time and cost. A significant emphasis is placed on integrating components where feasible, such as combining the kickstand and frame, to minimize loose parts and potential failure points. Using standardized fasteners across different assemblies reduces the inventory complexities and tooling requirements, facilitating a smoother assembly line operation. Additionally, the layout of components is strategically planned to ensure that each can be accessed easily and assembled with minimal effort, thereby enhancing ergonomic efficiency and reducing the labor intensity of the assembly process.

Concurrently, DFM selects the most appropriate materials and manufacturing techniques that balance cost, functionality, and durability. The frame and deck of the scooter are considered for different materials, such as aluminum for its lightweight and corrosion-resistant properties, versus steel for its durability and lower cost. Advanced manufacturing techniques like die-casting and CNC machining are evaluated for their precision and scalability. The choice of tire—pneumatic versus solid rubber—is analyzed with an emphasis on manufacturing ease and performance trade-offs. The paper also explores the production of braking systems and bearings, recommending processes that enhance component compatibility and performance while remaining economically viable.

Integrating DFA and DFM is critical in achieving a harmonious design that is easy to assemble and economical to manufacture. Prototyping is pivotal in this integration, allowing for real-time evaluation and iteration of design choices. Each prototype undergoes rigorous testing to ensure that assembly efficiency does not undermine the scooter's quality or functional integrity. Feedback loops from testing are used to refine both the design and the process, ensuring that each component aligns with the overarching goals of cost reduction and manufacturability.

Implementing DFA and DFM principles in designing and producing an electric scooter presents a case study in optimizing product design for mass production. The findings illustrate how targeted design choices can substantially lower production costs, decrease assembly times, and reduce material waste, thereby enhancing the market competitiveness of electric scooters. This approach benefits manufacturers by improving profitability and contributes to the sustainability of products by optimizing resource use and minimizing environmental impact. This project offers insights and methodologies that manufacturers can adopt to refine their production processes and enhance their commercial viability.

Figure 1: Electric Scooter [1],[2]

1. Introduction

Design for Manufacturing and Assembly (DFMA) is an engineering strategy aimed at designing products to simplify and optimize manufacturing and assembly processes. By employing DFMA principles, manufacturers can reduce production costs, minimize component counts and complexity, improve product quality and reliability, and shorten product development cycles. The electric scooter, a popular and environmentally friendly mode of transportation in urban settings, provides an ideal case study for DFMA due to its complexity and the variety of components it includes, such as the motor, battery, frame, and wheels.

The primary goal of DFMA is to identify, quantify, and eliminate waste or inefficiency in product design that could complicate the manufacturing and assembly processes. This means analyzing each component and assembly step for the electric scooter to determine if it can be redesigned or eliminated without reducing the scooter’s overall functionality and appeal. This analysis starts with a thorough examination of the scooter's total assembly time, which is crucial for understanding the labor inputs and, subsequently, the cost implications of the manufacturing process.

In the case of the electric scooter, the total assembly time is approximately 322.82 seconds, or roughly 5 minutes and 23 seconds. This figure includes both insertion and handling times, representing the manual effort required to assemble the scooter. Additionally, inspection time, a significant aspect of ensuring quality in the final product, accounts for 25% of the total assembly time, or about 80.7 seconds per scooter. This extended time in quality control underlines the complexity and precision required in assembling electric scooters.

Labor costs also play a crucial role in the economics of scooter production. Assuming a labor rate of $30 per hour, typical for the industry, the combined cost for assembly and inspection per scooter amounts to approximately $2.72 and $0.673, respectively. These figures help understand the baseline costs involved in scooter production which are critical for setting competitive but profitable pricing strategies. The DFMA approach can help streamline these processes and reduce costs. For example, redesigning components to decrease assembly difficulty or integrating functions into fewer parts to reduce the total number of components. This speeds up the assembly process and reduces potential errors and defects. Additionally, efficient design revisions can reduce the scooter's weight, improving its performance and energy efficiency and further enhancing product appeal.

Moreover, the analysis extends beyond mere cost reduction. DFMA encourages innovation by challenging designers and engineers to think about products in new ways. It often leads to more sustainable designs by minimizing waste and optimizing material use, which is especially significant in electric scooters where environmental impact is a key consumer concern.

After assembly, the journey of an electric scooter from manufacturing to the end consumer involves several stages, each adding to the final retail cost. These stages include storage, transportation, and handling by distributors and retailers, all of which incur additional costs. Understanding these supply chain dynamics is crucial for manufacturers when setting the final price. For instance, despite the production costs of $186.51 per scooter, the retail price on the official website is $440, a markup necessary to cover these additional supply chain expenses and ensure profitability.

Furthermore, DFMA helps identify areas where automation can be introduced into the assembly process, reducing reliance on manual labor and decreasing the probability of human error. Automating certain aspects of the assembly line can lead to more consistent product quality and faster production times, vital in maintaining a competitive advantage in the fast-paced consumer markets.

In conclusion, the DFMA analysis of an electric scooter provides insights into reducing costs and enhancing efficiency and pushes the boundaries of product innovation and sustainability. By simplifying design and optimizing manufacturing and assembly processes, companies can better meet the challenges of modern markets, satisfy consumer expectations, and maintain profitability. Understanding these principles and effectively applying them is fundamental to the success of any product in today’s competitive landscape.

Electric scooters have emerged as a versatile mode of urban transportation due to their convenience, eco-friendliness, and cost-effectiveness. The efficiency and performance of these scooters hinge significantly on their mechanical components. Here, we introduce the fundamental non-electronic elements that make up an electric scooter, explaining their functions and their pivotal roles in the overall utility and durability of the vehicle.

Figure 2: Electric Scooter Components [3]

1. Frame: The frame is the core structure of the scooter, typically crafted from metals such as aluminum or steel. It serves as the chassis that supports all other components, providing the necessary rigidity and strength while balancing weight for optimal maneuverability and efficiency. The choice of material and the design of the frame directly influence the scooter's durability, weight, and even its aesthetic appeal.

2. Fork: Attached to the front part of the frame, the fork holds the front wheel and is crucial for steering and absorbing shocks from uneven surfaces. This component's design is vital for the scooter's handling characteristics and safety, impacting how well the scooter responds to rider inputs and navigates through varying terrains.

3. Wheels: The scooter's wheels, comprising the rims and the hub, are usually made from lightweight metals or composite materials. They are central to the scooter's mobility, affecting its speed, stability, and the smoothness of the ride. The wheels' design and material are selected to balance strength and weight, enhancing performance without burdening the scooter with unnecessary heft.

4. Handle Gripper: Rubber grippers for handlebars are essential ergonomic components designed to enhance comfort and control for users of various vehicles, including electric scooters, bicycles, and motorcycles. These grippers, also known as grips or handle grips, are typically made from high-quality rubber materials that provide excellent durability and resistance to wear and tear.

5. Brakes: The braking system, including brake pads, calipers, and levers, is critical for rider safety. The system must reliably allow the rider to control speed and perform safe stops, whether disc or drum brakes. The efficiency of the brakes directly impacts the safety and control aspects of the scooter, making it a vital area for precision engineering and quality materials.

6. Handlebars: Handlebars are not just for steering; they also house brakes and acceleration controls in powered models. They must be ergonomically designed to provide comfort and ease of use, directly affecting the rider's ability to control the scooter effectively.

7. Deck: The deck is where the rider stands and must be sturdy and slip-resistant to ensure safety and comfort. It supports the rider's weight and is the main interface between the scooter and the user, making its design crucial for a secure and enjoyable ride.

8. Kickstand:

A seemingly simple component, the kickstand, allows the scooter to be parked upright when not used. Its convenience and functionality prevent the scooter from being laid on the ground, thus avoiding potential damage.

9. **Mudguards/Fenders:** Mudguards or fenders are protective components that shield the rider from water, mud, and debris thrown up by the rotating tires. They are crucial for maintaining rider comfort and scooter cleanliness in adverse weather conditions.

10. **Reflectors:** Plastic reflectors on electric scooters play a crucial role in ensuring the safety and visibility of riders, particularly in low-light conditions. These small yet significant components are vital for making the scooter conspicuous to other road users, thereby reducing the risk of accidents.

Each of these components is designed carefully for durability, weight, and ease of assembly. Their optimization can significantly enhance electric scooters' performance, safety, and appeal, marking critical areas for innovation in scooter design and manufacturing.

2.1. Frame/Deck:

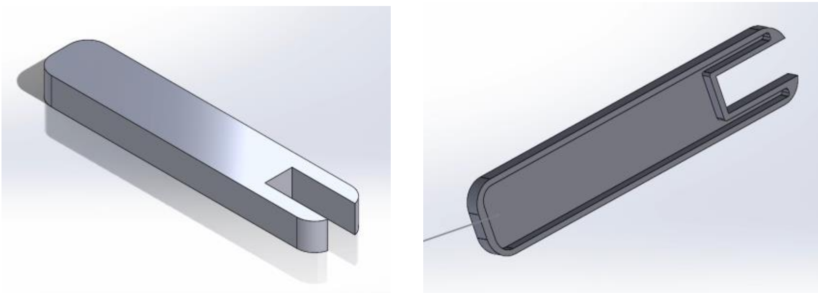


Figure 3: Deck (Main Frame)

The deck is usually made from aluminum or steel for strength and durability, although some high-end models may use carbon fiber or other advanced composites for a lighter weight. Aluminum is often preferred due to its combination of lightness and strength.

Engineers design the deck to withstand the weight of the rider and any additional forces encountered during riding. They must balance strength, weight, and cost. Computer-aided design (CAD) software is typically used to model the deck's shape, including where folds, holes, and mounts will be located. The material is cut into the rough shape of the deck using methods such as Die casting. It is then formed into the final shape using presses or by machining. This may involve bending the material to create the appropriate foot platform and edges. As a deck consists of multiple pieces, they may be welded together or fastened using bolts or rivets. Welding is common for metal decks to ensure a solid construction.

Final Assembly: Finally, the deck is fitted with grip tape, and any necessary components, such as folding mechanisms, battery compartments, and other fixtures, are installed. The finished deck undergoes quality control checks to meet safety standards and the manufacturer’s specifications.

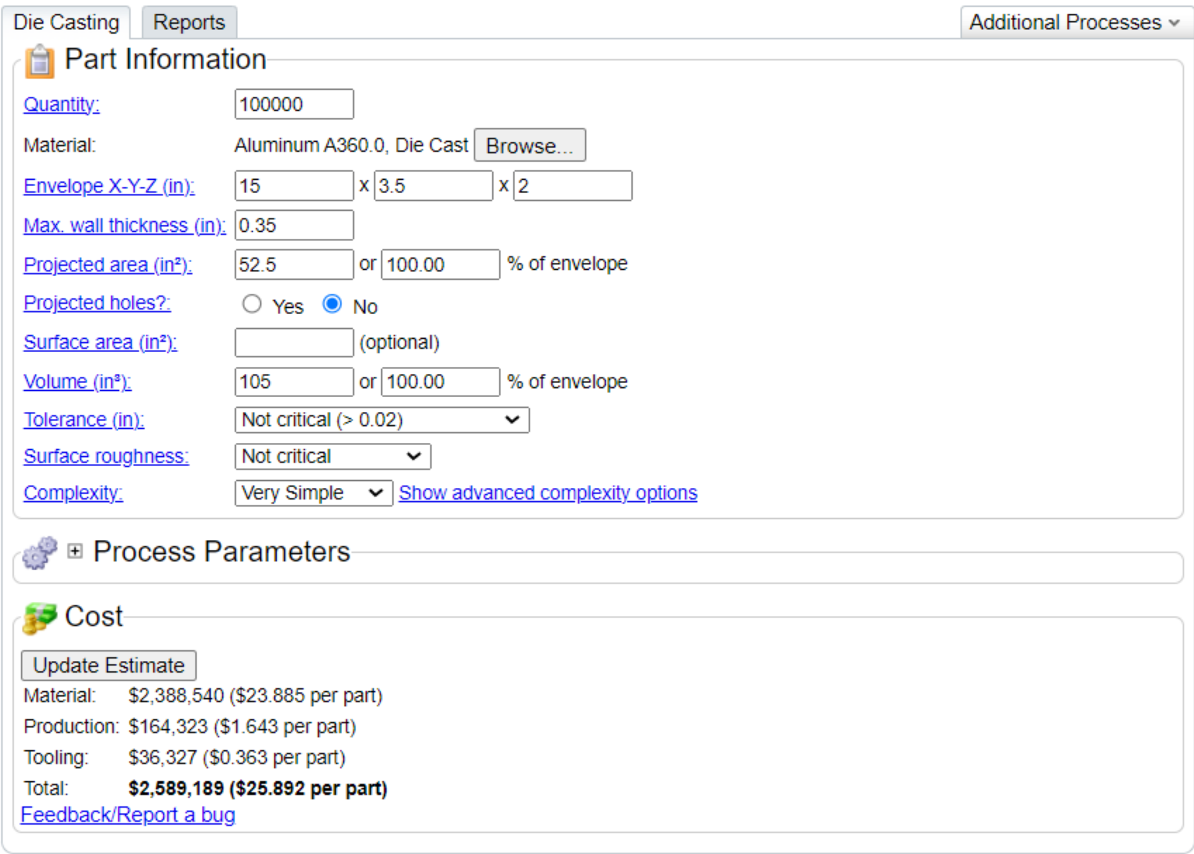


Figure 4: Deck Cost estimation

- **Material Selection:**

Aluminium A 360 is chosen for its exceptional properties suitable for die casting. This alloy provides high strength at high temperatures, superior corrosion resistance, pressure tightness, and excellent fluidity and pressure tightness. These properties make it ideal for components that require a good surface finish, high dimensional stability, and durability, such as those in electric scooters.

- **Selected Material vs. Other:**

Compared to aluminum alloys, A 360 has better corrosion resistance and mechanical properties at high temperatures. It also offers:

- Superior pressure tightness is crucial for components exposed to varying environmental conditions.
- Better die-filling characteristics allow for more complex shapes than other alloys such as A380 or A390, which might provide better wear resistance or easier processing but don't balance these traits as effectively as A360.

- **Selection of Manufacturing Process:**

Die casting was chosen because it is highly efficient for mass-producing metal parts with complex geometry. It offers:

- High production rates with excellent dimensional accuracy and smooth cast surfaces.
- Reduced need for machining and finishing, which lowers production costs.
- Ability to produce thinner walls and, hence, lighter components that are advantageous for the mobility of electric scooters.

- **Advantages of this Manufacturing Process over others:**

- High Production Efficiency: Die casting is highly suited for large-scale production due to its rapid cycle times. Once the die is designed and created, each casting can be produced very quickly, allowing for high-volume production with consistent quality.
- Cost-Effectiveness: Although the initial setup costs for die casting (including die design and creation) are high, the per-unit production cost is significantly reduced when spread over many units. This makes die casting economically viable for large production runs, as the initial costs are amortized over more units.
- Consistent Quality and Precision: Die casting produces parts with excellent dimensional accuracy and consistency. The process involves injecting molten metal into a mold under high pressure, which ensures that metal fills mold cavity and replicates the mold's exact shape and surface texture.
- Strength and Weight: The parts produced by die casting are stronger than those made by other casting methods because the high pressure used during casting reduces porosity and increases the density of the metal. Additionally, die casting allows for the production of parts with thin walls without sacrificing strength, which is ideal for electric scooters where weight reduction is crucial.

- **Advantages of this Re-design:**

The design shown incorporates features that reduce material usage and simplify assembly:

- Integrating multiple parts into a casting reduces assembly operations and material waste.
- The design may include features that optimize strength and material distribution, reducing overall material costs without compromising structural integrity.
- By using die casting, the need for secondary operations like welding or fastening is minimized, further reducing labor and production costs.

- **DFA and DFM Principle used:**

The design shown likely incorporates features that reduce material usage and simplify assembly:

- Integrating multiple parts into a casting reduces assembly operations and material waste.
- The design may include features that optimize strength and material distribution, reducing overall material costs without compromising structural integrity.
- By using die casting, the need for secondary operations like welding or fastening is minimized, further reducing labor and production costs.

Overall, the selection of Aluminium A 360 and the die casting process, combined with a thoughtfully designed component, result in a cost-effective solution for the demands of an electric scooter frame.

2.2. Mud Guard:

Figure 5: Mud Guard

Die Casting manufactures this part. The die is preheated and lubricated to facilitate the flow of molten metal and to aid in the ejection of the part after solidification. The metal alloy is melted in a separate furnace and then transferred to the die-casting machine. The molten metal is injected into the die under high pressure. This pressure is maintained until the metal solidifies. After the metal has been injected, it begins to cool and solidify quickly within the die. The die is opened once the metal has solidified, and the mudguard is ejected. The ejection mechanism often involves pins pushing the part out of half the die. Excess material, such as the sprue (the passage through which the molten metal flows), runners (the channels that connect the sprue to the part), and flash (excess thin layers of metal), are trimmed from cast mudguards. This is done manually or using a trimming die.

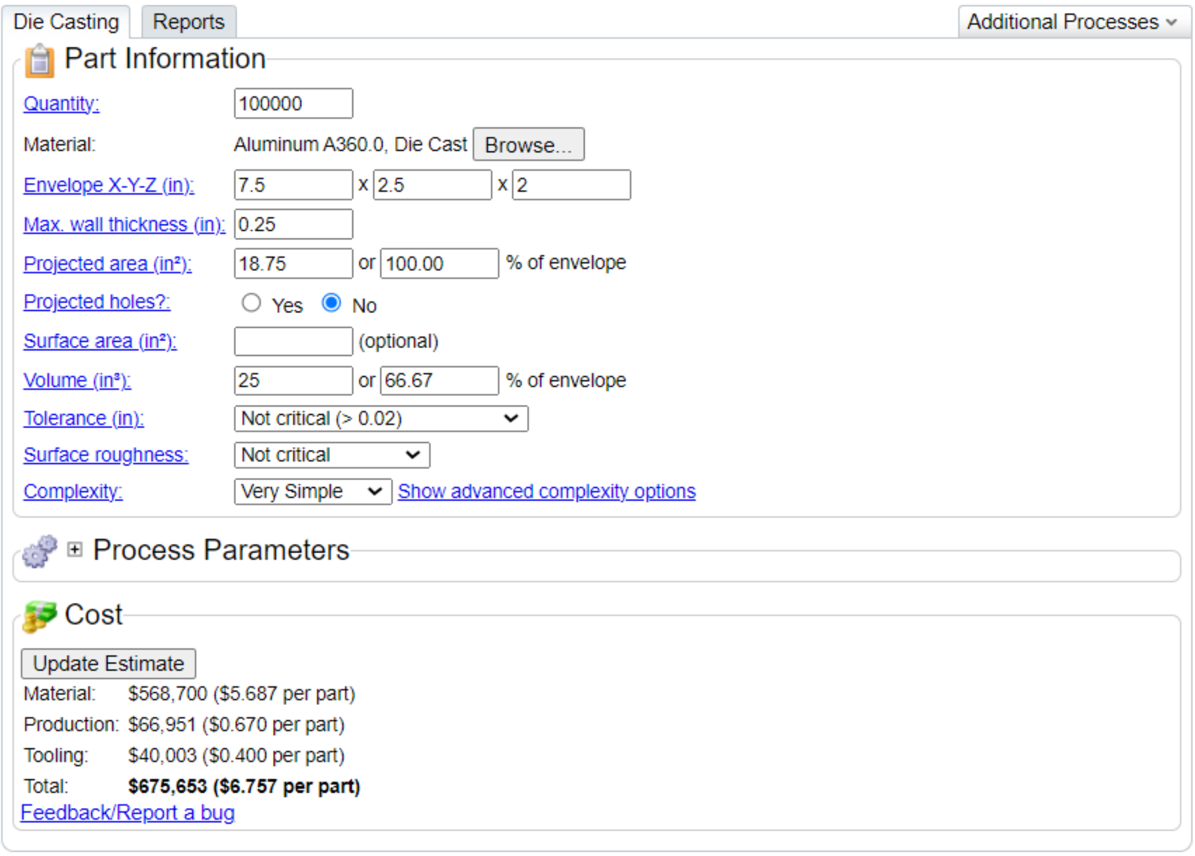


Figure 6: Cost Estimation for the Mud Guard

2.3. Side Stand (Redesigned):

Material Selected: Aluminum

Advantages of the Material Selected:

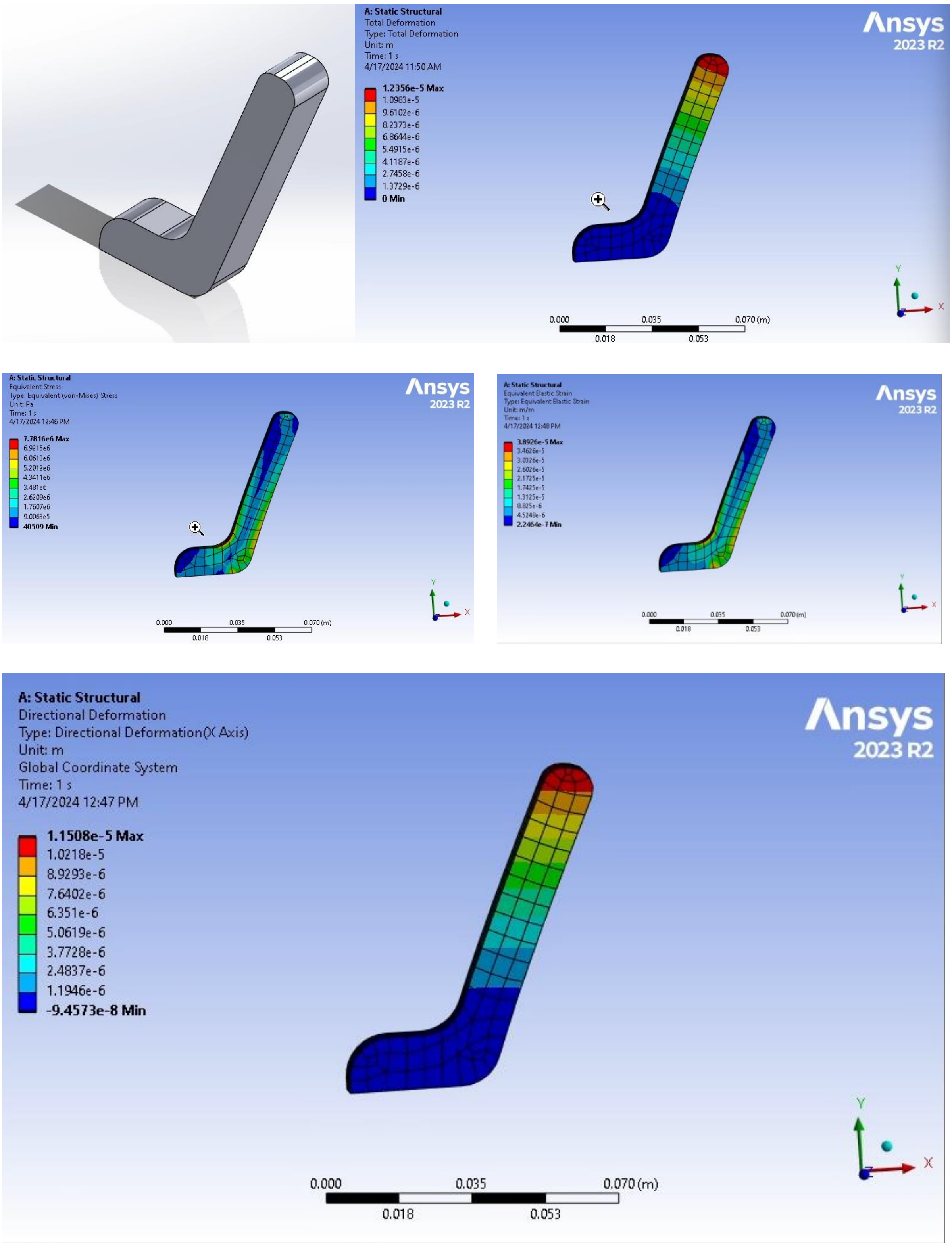


Figure 7: FEA of Side Stand

The above FEA verifies the suitability of the design to withstand the weight of the electric scooter.

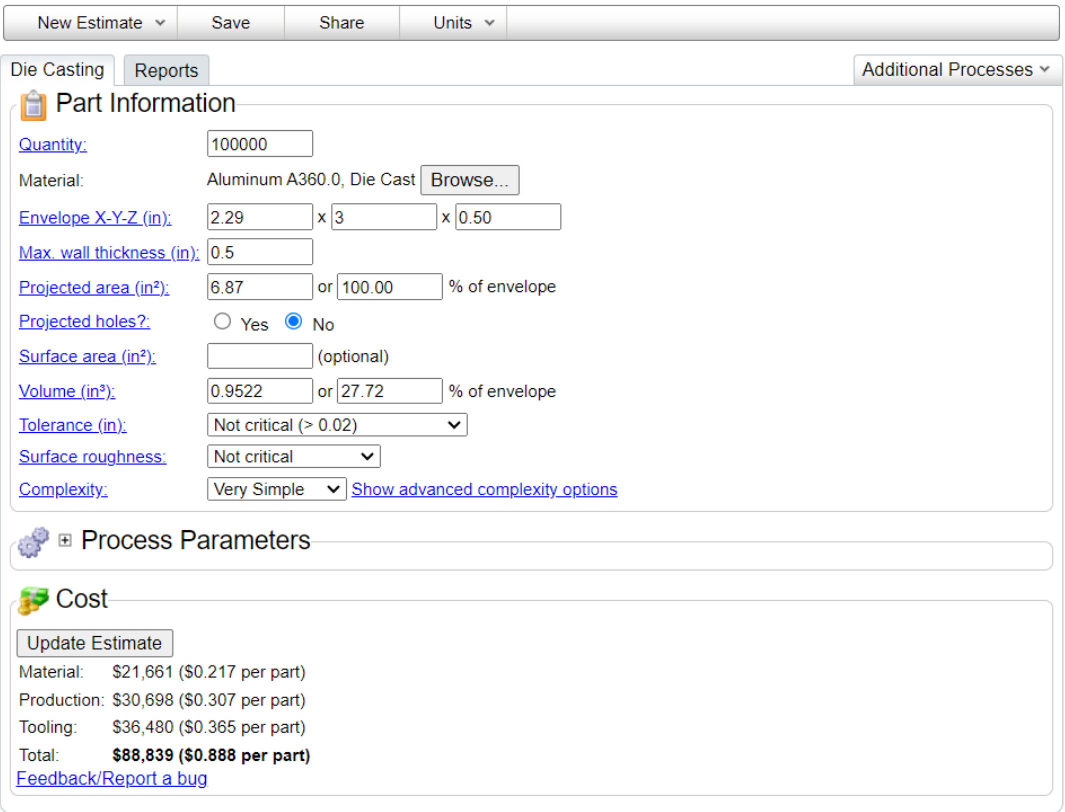


Figure 8: Cost Estimation of Side Stand (Die Casting)

A scooter stand provides essential support, ensuring stability when parked. It allows for space-efficient storage, which is especially valuable in crowded urban settings. Easily deployable, it protects the scooter from surface damage and facilitates the use of security measures by maintaining a stable position for locking immovable objects.

FEA shows that the redesigned geometry and thickness can withstand the scooter's weight efficiently.

➢ **Material Selection:**

Aluminium A 360 was selected for its excellent properties suited for die casting:

- High Strength and Durability: Crucial for a component like a scooter stand that must withstand repeated mechanical stress and environmental exposure.
- Good Corrosion Resistance: Ensures longevity and resistance against weather elements, which is particularly important for outdoor use.
- Excellent Fluidity and Pressure Tightness: Allows for producing complex shapes with precise dimensional accuracy, which is essential for the integrated design of a scooter stand.

➢ **Selected Material vs Other:**

Aluminium A 360 is superior to other aluminum alloys due to:

- Better Thermal Properties: Ensures stability in varying temperatures, which is beneficial for outdoor equipment.
- Superior Corrosion Resistance and Finish: Compared to other alloys like A380, which might offer slightly easier processing but less resistance to corrosion and a lower-quality surface finish.
- Optimal Balance of Performance and Cost: While other materials like steel could offer higher strength, they would increase the weight and might not provide the same level of corrosion resistance without additional coatings.

➢ **Selection of Manufacturing Process:**

Die casting is ideal for efficiently and precisely producing large volumes of metal parts with complex geometry. It was chosen for reasons including:

- Efficiency in High-Volume Production: Perfect for manufacturing 100,000 units due to rapid production capabilities.
- Precision and Consistency: Allows the integration of fine details directly into the part without additional machining.
- Reduced Waste: Minimizes excess material use through precision molds.

➢ **Advantages of this Manufacturing Process over others:**

- Cost Efficiency: Lower per-unit cost when amortizing the high initial tooling costs over large production volumes.
- Rapid Production Time: A high-speed production cycle helps meet large order demands quickly.
- Quality Assurance: High-pressure casting produces high-density, strong parts with minimal porosity.

➢ **Advantages of this design in comparison to conventional design:**

- Integration of Features: Incorporates multiple functions and connections into a single component, reducing the number of parts and assembly operations needed.
- Reduced Material Usage: Designed to use the minimum amount of material necessary for required strength, decreasing material costs.
- Minimized Finishing Needs: The excellent surface finish directly from the die-casting process reduces or eliminates the need for secondary finishing processes.

➢ **DFA and DFM Principles used:**

- **Design for Assembly (DFA):** Simplifies assembly processes by reducing the number of parts and potentially eliminating fasteners using snap-fit or integral joint designs.
- **Design for Manufacturing (DFM):** Focuses on ensuring that the stand can be manufactured efficiently through die casting. This includes considerations like draft angles, fillet radii to reduce stress concentrations, and uniform wall thicknesses to prevent defects such as cold shuts and misruns.

By utilizing these principles and choices, the design and manufacturing process of the electric scooter stand is optimized for functionality, durability, cost efficiency, and manufacturability.

2.4. ABS Handle Gripper:

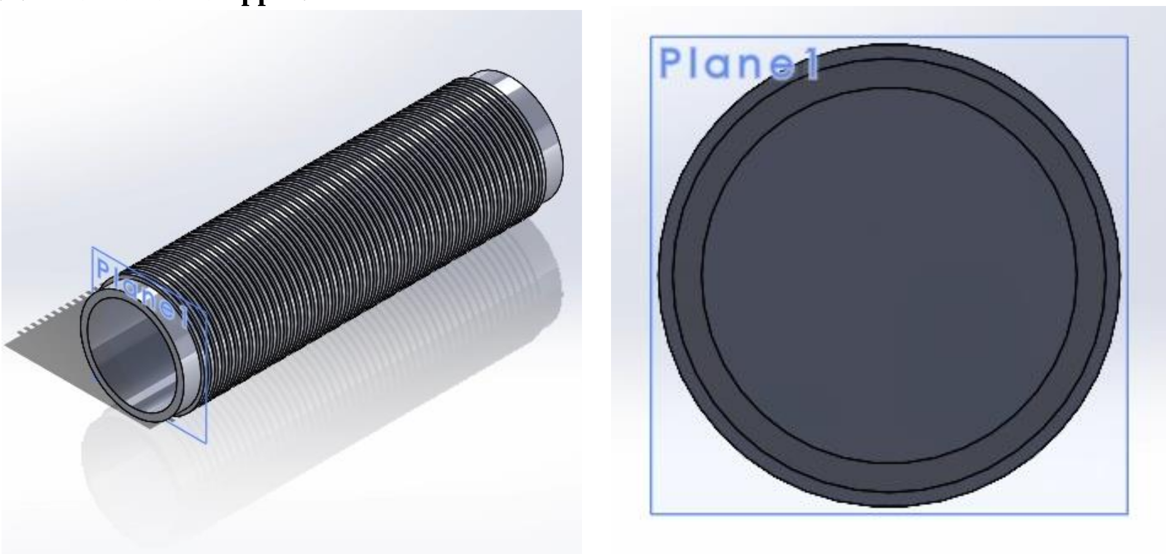


Figure 10: ABS Handle Gripper

Diameter: 1.1 inches; Length: 8.661 inches; Thickness: 0.157 inches
Material: ABS
Manufacturing Process: Injection Molding

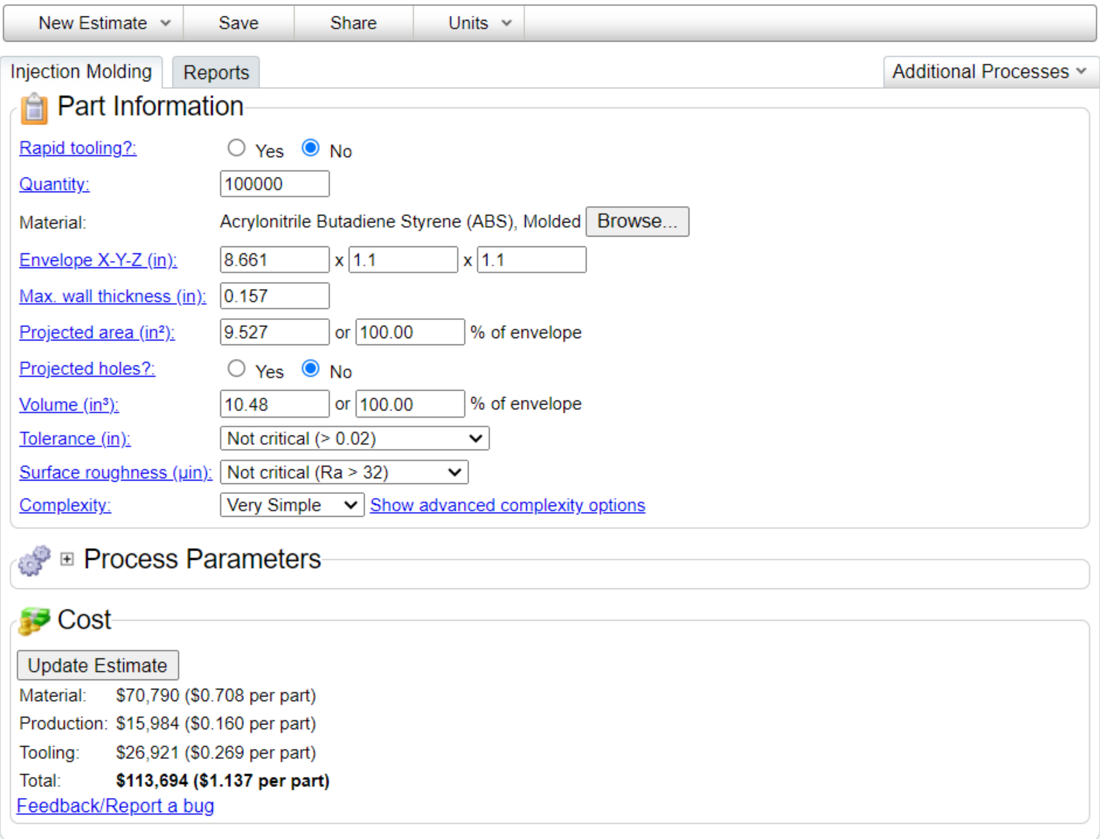


Figure 11: Cost Estimate for Handle Gripper

An ABS gripper on an electric scooter enhances rider control and safety. Made from durable ABS plastic, it offers a strong, non-slip surface for secure handling, especially in adverse weather conditions. This component is crucial for maintaining grip and steering precision, significantly boosting the scooter's overall usability and safety.

- **Material Selection:**

ABS (Acrylonitrile Butadiene Styrene) was chosen for its excellent toughness, rigidity, and strength combination. It also offers good resistance to impact and abrasion, which are crucial for a handle gripper on an electric scooter that requires durability and a comfortable grip. ABS (Acrylonitrile Butadiene Styrene) is an ideal material for applications that balance strength, toughness, and aesthetic quality. Its outstanding impact resistance makes it perfect for durable goods like electric scooter handle grips, which must withstand regular handling and exposure to environmental stresses. ABS also excels in dimensional stability, ensuring that products maintain shape under stress and over time. Additionally, it can be easily colored during production, offering aesthetic flexibility without compromising the product's physical integrity. Its thermal properties allow it to perform well in varying temperatures, enhancing its suitability for outdoor use.

- **Selected Material vs Other:**

Compared to alternatives like PVC or Polypropylene, ABS is superior because:

- Higher toughness and impact resistance: Important for a handle that undergoes frequent stress.
- Better temperature and chemical resistance: Ensures durability under varying environmental conditions.
- Good dimensional stability and surface finish: Offers a more aesthetically pleasing and functional product.

- **Selection of Manufacturing Process:**

Injection molding was selected because it is ideal for producing high volumes of complex plastic parts with high accuracy and repeatability. This process allows for:

- Consistent quality: High precision in replicating detailed designs.
- Efficient production: Fast cycle times suitable for large-scale manufacturing.
- Material and color flexibility: Allows the incorporation of various colors and material properties directly during manufacturing.

- **Advantages of this Manufacturing Process over others:**

- Cost-effectiveness: High initial setup costs (mold design and creation) are offset by the low per-unit cost in high-volume production.
- Speed of production: Rapid production cycles enable meeting large orders efficiently.
- Less waste: Excess material can often be recycled, reducing waste and often lowering.

- **Advantages of this design in comparison to conventional design:**

- Integrated features: Design elements like texturing for grip, contours for comfort, and end caps can be molded in one piece without the need for additional components.
- Reduced labor: Automation in injection molding reduces the need for labor, lowering the cost of assembly and post-production.
- Tooling investment: Though high, is quickly amortized over large production volumes, reducing the impact on the unit cost.

- **DFA and DFM Principles used:**

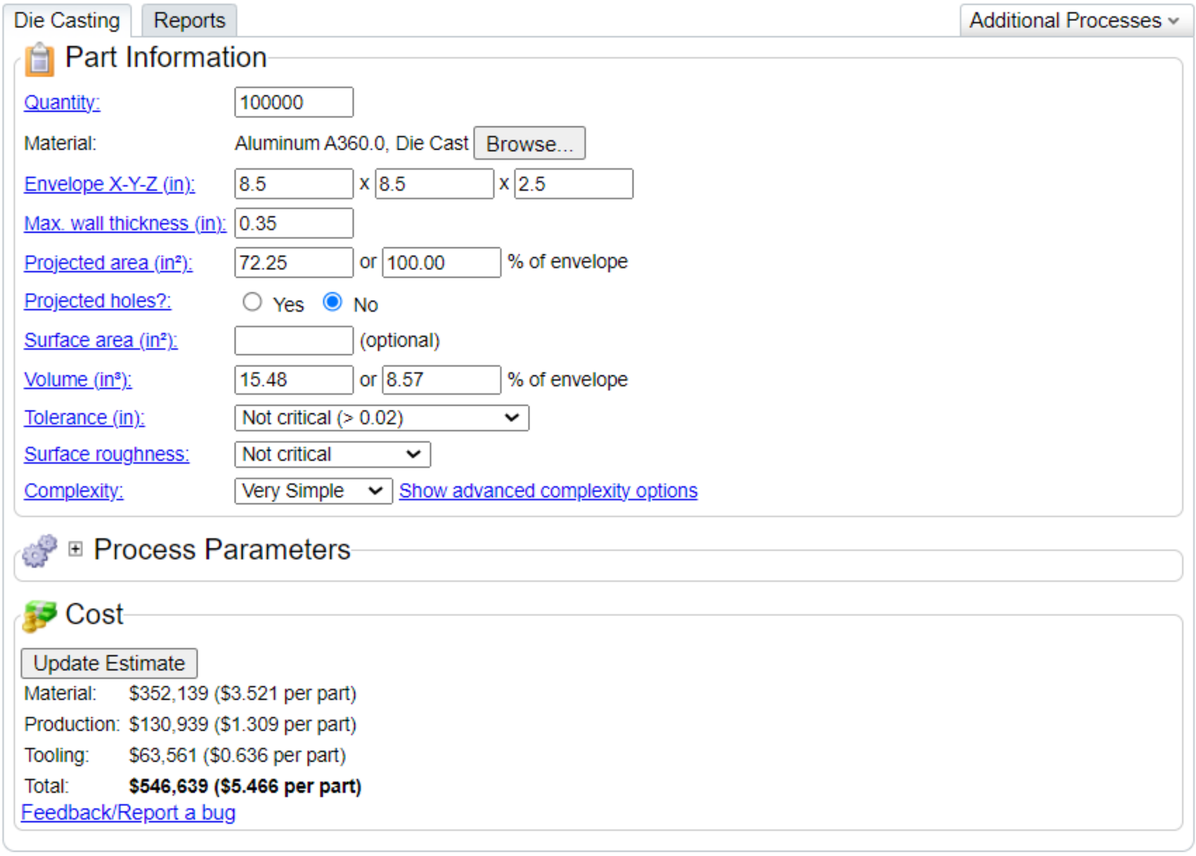
- Design for Assembly (DFA): The design minimizes assembly requirements by integrating multiple functions into the single molded part, such as incorporating non-slip textures and ergonomic features directly into the handle gripper.
- Design for Manufacturing (DFM): The design is optimized for the injection molding process, ensuring proper mold flow, cooling, and ejection. Features like uniform wall thickness and draft angles are included to prevent defects such as warping or sink marks and facilitate easy ejection from the mold.

This combination of material selection, manufacturing process, and thoughtful design optimization ensures the ABS handle gripper is both cost-effective and functional for its application on electric scooters.

2.5. Wheels Rims:

Figure 12: Scooter Rims

Diameter: 8.5 inches; Width: 2.56 inches; Weight: 650 grams.
Material: Aluminium
Manufacturing Method: HPDC


Die Casting | Reports | Additional Processes

Part Information

Quantity:	100000
Material:	Aluminum A360.0, Die Cast Browse...
Envelope X-Y-Z (in):	8.5 x 8.5 x 2.5
Max. wall thickness (in):	0.35
Projected area (in²):	72.25 or 100.00 % of envelope
Projected holes?:	Yes / No (selected)
Surface area (in²):	(optional)
Volume (in³):	15.48 or 8.57 % of envelope
Tolerance (in):	Not critical (> 0.02)
Surface roughness:	Not critical
Complexity:	Very Simple Show advanced complexity options

Process Parameters

Cost

Update Estimate

Material:	$352,139 ($3.521 per part)
Production:	$130,939 ($1.309 per part)
Tooling:	$63,561 ($0.636 per part)
Total:	**$546,639 ($5.466 per part)**

Feedback/Report a bug

Figure 13: Cost Estimate for Wheel Rim

Aluminum wheel rims for electric scooters provide a lightweight yet robust solution for sustainable mobility. These rims enhance performance by reducing overall weight, thus improving acceleration and range. Aluminum's corrosion resistance ensures durability, while its ability to dissipate heat helps maintain optimal tire conditions for safer, smoother rides.

- **Material Selection:**

Aluminium A360 was chosen for its exceptional die casting properties. It offers excellent corrosion resistance, high strength, and good thermal conductivity. The material also provides a high-quality surface finish and maintains dimensional stability under heat, essential for components like wheel rims that must endure significant environmental and operational stresses. This alloy is also fully recyclable, supporting sustainability in manufacturing practices. Its ability to achieve fine details in die casting ensures that complex designs are executed with precision, enhancing both functionality and aesthetic appeal of the scooter.

- **Selected Material vs Other:**

Compared to other materials such as steel or other aluminum alloys:

- A360 vs Steel: Aluminium A360 is significantly lighter than steel, reducing the scooter's overall weight, which can lead to better handling and efficiency. Unlike steel, A360 does not require additional treatments to prevent rust.
- A360 vs Other Aluminium Alloys: While alloys like A380 might offer slightly easier processing, A360 provides better corrosion resistance and surface finish, which are crucial for the aesthetic and longevity of exterior scooter parts like wheel rims.

- **Selection of Manufacturing Process:**

Die casting was selected due to its ability to produce complex shapes with high precision and excellent surface finish. The process is highly efficient for mass production, making it ideal for manufacturing components like wheel rims where dimensional accuracy and smooth contours are important. Die casting, utilized for manufacturing the electric scooter wheel rim, excels in producing complex parts with tight tolerances and excellent surface finish. This process allows for the integration of multiple features into a single component, reducing assembly time and cost. Its high-speed production capability is ideal for meeting large volume demands efficiently, ensuring consistent part quality across extensive production runs.

- **Advantages of this Manufacturing Process over others:**

- Speed and Efficiency: Die casting allows for the rapid production of large quantities with minimal downtime between casts.
- Cost-Effectiveness: The per-unit cost becomes very competitive for large production runs due to the reduced need for secondary machining and finishing.
- Consistency and Quality: Produces parts with high dimensional accuracy and uniformity, which are essential for assembling mechanical components like wheel rims.

- **Advantages of this design in comparison to conventional design:**

- Integrated Features: The design may integrate multiple features, reducing the number of parts required in the wheel assembly.
- Material Efficiency: Optimized design can use less material while maintaining structural integrity, further reducing costs.
- Reduced Assembly Costs: A simpler design means fewer steps in assembly, lowering labor costs.

- **DFA and DFM Principles used:**

- **Design for Assembly (DFA)**: The wheel rim design likely minimizes the use of fasteners and reduces the complexity of assembly. This can be achieved by creating easily aligned features and fitting them together seamlessly.
- **Design for Manufacturing (DFM)**: The wheel rim design considers the die-casting process's capabilities and limitations. This includes designing to avoid undercuts, maintaining uniform wall thicknesses to prevent hot spots, and ensuring proper placement of gates and overflows to achieve optimal metal flow and cooling.

These considerations make Aluminium A360 and the die casting process particularly well-suited for the manufacturing of electric scooter wheel rims, especially for high-volume production scenarios.

2.6. Brake Lever and Housing

The working principle of a brake lever in systems like a bicycle with disc brakes or a scooter without regenerative braking primarily involves a mechanical process that translates the force applied by the hand into stopping power. When the brake lever is squeezed, it pivots around a fulcrum positioned on the handlebar, initiating the force application. This action, depending on the system, either pulls a cable or pushes fluid through a hydraulic line. In cable-operated brakes, which are common in many bicycles and some scooters, pulling the lever tightens the cable that runs from the lever to the brake Callipers near the wheel. This tension moves the brake components, engaging the braking mechanism. In hydraulic systems, squeezing the lever increases the pressure in the fluid within the lines, which in turn activates the Callipers at the wheel to press the brake pads against the disc. This friction between the brake pads and the disc slows down or stops the wheel, effectively allowing the rider to control the speed or halt the vehicle. This method of braking is effective because it directly applies physical force to reduce the wheel's motion without relying on electrical or regenerative processes.

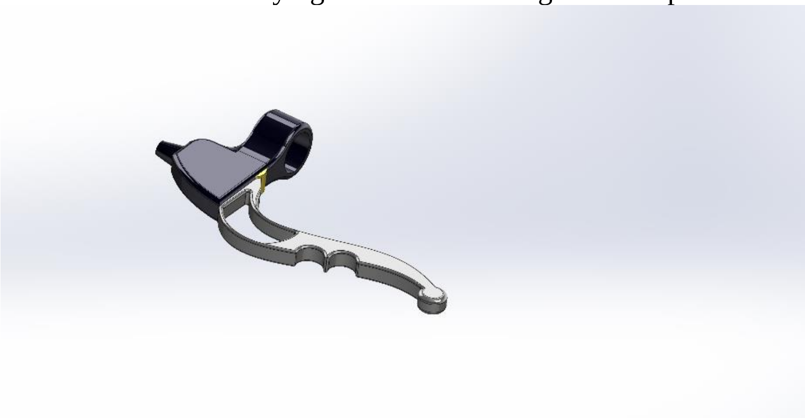


Figure 14: Brake Lever and Housing

MATERIAL

When selecting materials for the brake levers of electric scooters, Aluminium 6061 T6 alloy stands out as the optimal choice due to its superb blend of performance, cost efficiency, and lightness. This material is favored for its exceptional strength-to-weight ratio, ensuring that the brake levers are both lightweight and robust, thus providing the rider with precise control and responsiveness during braking. Moreover, Aluminium alloy exhibits excellent resistance to corrosion, which is crucial for maintaining the integrity and longevity of the brake levers in various weather conditions.

Aluminium strikes a middle ground in cost, offering higher performance than cheaper materials without the premium price tag of more exotic options like titanium. This makes it a cost-effective solution for budget-conscious and performance-oriented scooter models, ensuring broad accessibility and appeal.

Aluminum alloy is highly favored for manufacturing the lever body of brake levers on electric scooters due to its exceptional strength-to-weight ratio. This critical property ensures that Aluminium, while being lightweight, also maintains a high level of strength, which is essential for the durability and reliability of the brake system. The lightweight nature of Aluminium contributes to the overall reduction of the scooter's weight, enhancing its maneuverability and efficiency. Simultaneously, its robustness allows it to withstand the mechanical stresses associated with frequent braking actions without deforming, ensuring long-term reliability.

From a manufacturing standpoint, Aluminium is relatively affordable and widely available, making it an economically viable option for both high-volume and specialized production runs. Its ease of machining is another significant advantage, as it can be readily cut, drilled, and shaped into the intricate designs necessary for brake lever components, which helps keep production costs down. Additionally, Aluminium's compatibility with various machining processes ensures that manufacturers can achieve the precise specifications required for optimal brake performance.

Moreover, Aluminium's versatility extends to its finishing options, enhancing its functional and aesthetic qualities. Anodizing, one of Aluminum's most popular finishing techniques, not only improves its corrosion resistance—making it more durable in diverse weather conditions—but also allows for aesthetic customization. Through anodizing, Aluminium can be colored in a wide range of hues, enhancing the visual appeal of the brake levers and allowing for greater personalization or branding options. This combination of functional durability, cost-effectiveness, and aesthetic versatility makes Aluminium alloy an outstanding material choice for the brake lever bodies of electric scooters, balancing performance, cost, and style effectively.

SELECTED MATERIALS VS OTHER OPTIONS

Aluminium Alloy vs. Steel

• Weight: Aluminium alloy is significantly lighter than steel, which reduces the scooter's overall weight, enhancing its energy efficiency and maneuverability.
• Corrosion Resistance: Aluminium naturally resists corrosion better than steel, which can rust unless treated or coated, requiring less maintenance and offering longer life.
• Strength-to-Weight Ratio: Although steel is generally stronger than Aluminium, Aluminium's strength-to-weight ratio is superior, making it an excellent choice for balancing durability and ease of use.
• Handling: The lighter weight of aluminium alloy makes the scooter easier to handle, particularly regarding steering and stopping responsiveness.
• Cost: While high-grade alloys like stainless steel can be expensive, Aluminium offers a cost-effective alternative that provides high performance without the high price.
• Environmental Impact: Aluminium is more environmentally friendly regarding production and recycling. It requires less energy to produce and recycle compared to steel.
• Thermal Conductivity: Aluminium disperses heat more effectively, which can be beneficial in reducing the buildup of heat from friction in the braking system.
• Aesthetics: Aluminium can be finished in various ways (e.g., anodizing, painting), allowing for better customization and aesthetics than the typical painted or coated steel.

MANUFACTURING PROCESS

Process for the brake lever.

Cold chamber die casting is an excellent choice when manufacturing 100,000 brake levers using Aluminium 6061-T6. Aluminum 6061-T6 is a popular alloy for automotive and motorcycle components, including brake levers, due to its high strength-to-weight ratio, good corrosion resistance, and excellent machinability.

The T6 temper designation indicates that the alloy has been heat-treated and artificially aged, resulting in enhanced mechanical properties. This heat treatment process improves the alloy's yield strength, ultimate tensile strength, and hardness, making it suitable for applications that require high strength and durability, such as brake levers.

Cold chamber die casting is particularly well-suited for processing Aluminium 6061-T6. The alloy's relatively high melting point (around 650°C or 1200°F) is compatible with the cold chamber process, which typically operates at temperatures between 650°C and 750°C (1200°F to 1382°F). This ensures that the alloy can be easily melted and injected into the mold cavity under high pressure, resulting in a precise and detailed casting.

The high pressure used in cold chamber die casting also helps to minimize porosity and ensure a dense, uniform microstructure in the cast part. This is crucial for maintaining the strength and integrity of the brake lever, as any voids or defects could compromise its performance and safety.

Another advantage of using Aluminium 6061-T6 in cold chamber die casting is its good fluidity. This property allows the molten alloy to fill the mold cavity completely, even in areas with thin walls or intricate features. This is important for brake levers, as they often have complex geometries and require consistent wall thickness to optimize strength and weight.

After the die casting process, Aluminium 6061-T6 brake levers can be easily machined, drilled, or tapped if necessary. The alloy's excellent machinability allows for the creation of precise mounting points, cable guides, or other features that may be required for the brake lever's installation and function.

Finally, Aluminium 6061-T6 offers good corrosion resistance, which is essential for brake levers exposed to various weather conditions and road debris. The alloy forms a thin, protective oxide layer on its surface that helps to prevent further oxidation and corrosion, ensuring the longevity and reliability of the brake lever.

In summary, cold chamber die casting is an ideal manufacturing process for producing 100,000 brake levers using Aluminium 6061-T6. The alloy's high strength, good corrosion resistance, and excellent machinability, combined with the precision and efficiency of the cold chamber die-casting process, make it a perfect choice for high-volume production of these critical safety components.

Process for Brake Lever Body

Cold chambers die casting is ideal for producing 100,000 brake lever housings made from Aluminium 6061-T6 units. This process offers several advantages that make it well-suited for high-volume production of Aluminium parts with complex geometries and high-quality requirements.

Aluminum 6061-T6 is a popular alloy for automotive and motorcycle components, including brake lever housings, due to its excellent mechanical properties, corrosion resistance, and machinability. The T6 temper designation indicates that the alloy has been heat-treated and artificially aged to achieve optimal strength and hardness. Cold chambers die casting is compatible with this alloy, as it can handle the relatively high melting point of Aluminium 6061-T6 (around 650°C or 1200°F) without causing excessive wear or erosion to the injection system components.

In the cold chamber die-casting process, molten Aluminium is ladled into a shot sleeve from an external furnace for each casting cycle. A hydraulically driven plunger then pushes the molten metal from the shot sleeve into the die cavity under high pressure, typically ranging from 1,500 to 25,000 psi (10 to 175 MPa). This high pressure ensures that the molten Aluminium fills the die cavity and solidifies quickly, resulting in a precise and detailed casting with minimal shrinkage or porosity.

One of the key advantages of cold chamber die casting for brake lever housing production is its ability to produce parts with complex geometries and thin walls. This is essential for optimizing the housing's strength, stiffness, and weight while accommodating features such as mounting points, cable guides, and reinforcing ribs. The high pressure used in the process allows the molten Aluminium to flow into even the most intricate details of the die cavity, ensuring accurate and consistent replication of the desired geometry.

Advantages of this process over other process

- **High Production Rate:** Cold chamber die casting has a significantly higher production rate than machining, forging, and sand casting. The automated process and permanent molds allow for faster cycle times, typically ranging from a few seconds to a minute per part. This makes cold chamber die casting ideal for high-volume production, as it can efficiently produce large quantities of brake levers and housings quickly.
- **Design Flexibility**: Cold chamber die casting offers excellent design flexibility, allowing the production of parts with complex geometries, thin walls, and intricate details. This is particularly advantageous for brake levers and housings, which require specific geometries for optimal performance, strength, and fitment. Die casting can produce these complex features in a single step, reducing the need for multiple manufacturing operations.
- **Dimensional Accuracy and Consistency:** The high pressure and precise control of the cold chamber die-casting process result in parts with tight tolerances and excellent dimensional accuracy. This is crucial for brake levers and housings, as they must fit and function properly within the larger braking system. Die casting ensures consistency between parts, minimizing variability across the high-volume production run.
- **Material Efficiency:** Cold chambers die casting is a near-net-shape process, meaning that the parts produced are close to their final shape and require minimal post-processing. This results in less material waste than machining processes, which start with solid blocks or bars of Aluminium and remove material to achieve the desired shape. The higher material efficiency of die casting reduces raw material costs and environmental impact.

- **Superior Surface Finish**: Cold chambers die casting typically produces parts with a high-quality surface finish. The fine grain structure of the die cast Aluminium and the use of precision-machined dies contribute to a smooth surface that requires less post-processing, such as grinding or polishing, compared to forging or sand casting.
- **Cost-Effectiveness:** The combination of high production rates, lower tooling costs compared to forging, better material efficiency, and reduced post-processing requirements make cold chamber die casting a cost-effective choice for high-volume production of brake levers and housings. The process minimizes production time and costs while delivering high-quality parts that meet the required specifications.
- **Aluminium 6061-T6 Compatibility:** Cold chamber die casting is well-suited for processing Aluminium 6061-T6, which is a popular choice for brake levers and housings due to its excellent strength-to-weight ratio, corrosion resistance, and machinability. The process can handle the relatively high melting point of this alloy without causing excessive wear or erosion to the injection system components, ensuring consistent quality throughout the high-volume production run.

Justifications for key dimensions that are used to reduce cost

- **Material Thickness:** The 0.4 inch thickness is likely a carefully chosen value that balances structural integrity with material cost. It's thick enough to ensure the lever can withstand the forces exerted during braking without bending or breaking, yet not so thick as to be unnecessarily heavy or wasteful of material. Aluminium's strength means less material can be used than other metals, such as steel, without compromising the part's functionality.
- **Lever Length**: The 7-inch length of the lever provides sufficient leverage to allow the user to apply ample force to the braking system with minimal effort. This length is a compromise between providing enough leverage for easy operation and not being so long as to be unwieldy or increase the risk of snapping. The extended length also distributes the force over a larger area of the hand, improving comfort.
- **Ergonomic Design:** The contour and form of the lever are designed for proper holding, which means they need to conform to the shape of the hand when gripping. This ergonomic design helps in reducing rider fatigue and ensures that the rider can apply the necessary force without discomfort during prolonged use.
- **Cost-Effective Production:** By choosing dimensions that optimize material use and allow for efficient die casting, as previously discussed, production costs can be reduced. The 0.4-inch thickness ensures that the lever is not overbuilt, saving on material costs, while still providing sufficient strength due to the material properties of Aluminium.
- **Material Selection:** Aluminium is chosen for both the lever and the housing because it is less expensive than other high-performance materials like carbon fiber or titanium but still offers excellent performance characteristics such as good strength and corrosion resistance.
- **Manufacturing Considerations:** The chosen dimensions are likely influenced by manufacturing constraints and capabilities, such as the minimum wall thickness that can be achieved reliably during die-casting and the size of the die-casting equipment available.
- **Surface Area and Heat Dissipation**: The thickness and length of the lever also play a role in heat dissipation. Aluminium has good thermal conductivity, and the dimensions of the lever's surface area helps dissipate heat generated by friction in the braking system.
- **Integration with Other Components:** The dimensions must also consider the integration with the rest of the braking system, including how the lever interfaces with the handlebar, the brake cable or hydraulic system, and any adjustment mechanisms. The 0.4-inch thickness ensures enough surface area for secure attachments and adjustability.

DFA principle

- **Minimize Material Usage:** Use the least material required to achieve the necessary strength and functionality, like the 0.4-inch thickness that balances material cost with durability.
- **Simplify Geometry**: Keep part shapes simple to facilitate easy manufacturing. Complex shapes can increase manufacturing time and costs.
- **Standardize Components:** Use standard sizes and features where possible to reduce the need for custom tooling and to benefit from economies of scale.
- **Optimize Tolerances:** Only specify tight tolerances where necessary for the function of the part, as tighter tolerances can significantly increase manufacturing complexity and cost.
- **Consider Material Properties:** Choose a material like aluminium that is easy to work with in terms of machining and finishing and meets performance requirements.
- **Facilitate Efficient Machining:** Design parts to be easily machinable with standard cutting tools, minimizing the need for complex and time-consuming operations.
- **Eliminate Undercuts:** Undercuts require more complex tooling and can complicate the casting process. They should be avoided or minimized unless essential for the function of the part.

Part Cost Estimator

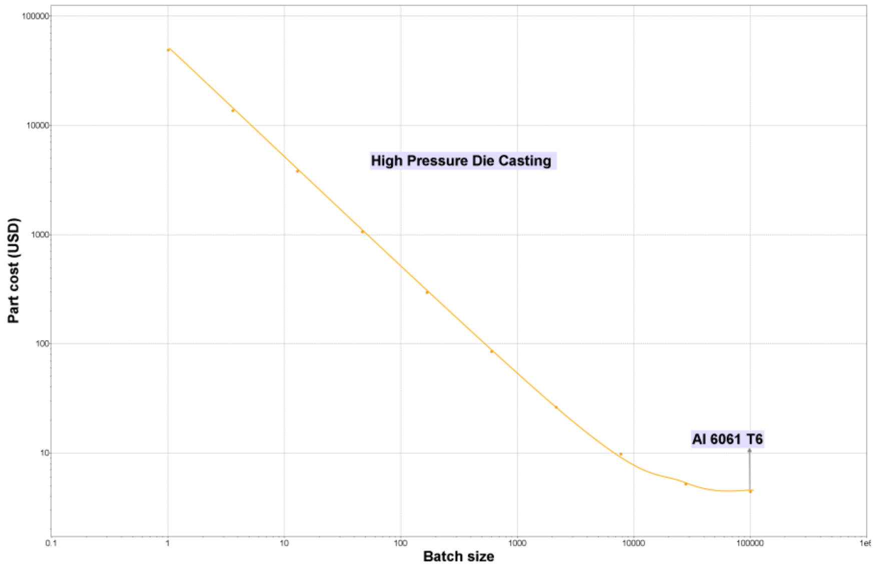


Figure 15 : Brake lever and housing Part cost vs Batch Size

The cost estimation process utilizing the Granta Edu pack involved a comprehensive analysis of several key factors influencing the production expenses of each part. These factors included considerations such as the material composition of the part, its shape complexity, and whether it underwent primary manufacturing processes, secondary processes, or a combination of both. Additionally, parameters such as the mass and length of the product and the envelope volume it occupies were taken into account to gauge the manufacturing requirements accurately.

Furthermore, details about the manufacturing processes employed, including any specialized techniques or equipment used, were factored into the cost estimation process. Considering these diverse elements, a thorough assessment of the production costs for each part was achieved.

Upon applying these parameters and analyzing the batch size of 100,000 units, the estimated cost per part was determined to be $4.2. This figure represents the culmination of a detailed evaluation encompassing various facets of the manufacturing process, ultimately providing a comprehensive understanding of the cost implications of producing the specified quantity of parts.

2.7. BRAKE DISC AND CALIPERS

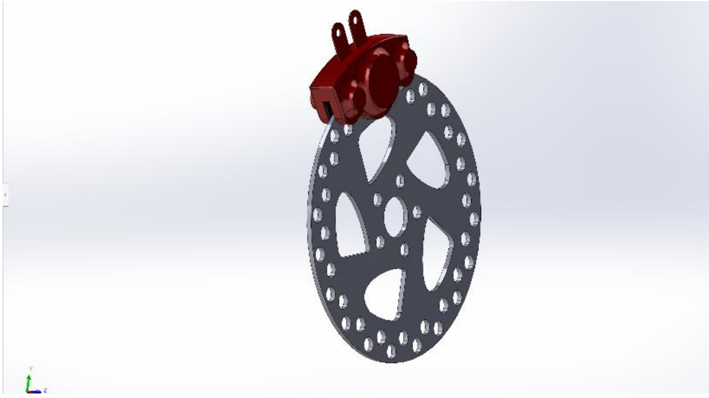


Figure 16: Brake disc callipers

The disk and Callipers braking system, widely used in conventional bicycles and electric scooters, operates on a principle that leverages mechanical force to achieve effective braking. The system comprises four main components. Firstly, the rotor, also known as the disk, is a flat, circular metal disc mounted directly onto the wheel's hub. This rotor spins with the wheel as the bicycle or scooter moves. Secondly, the Callipers, which is mounted over the rotor, holds the brake pads and includes a mechanism to move these pads toward and away from the rotor. Thirdly, the brake pads within the Callipers are crucial for the braking process; they are made from a high-friction material that is designed to endure heat and pressure.

When the rider applies pressure to the brake lever, typically located on the handlebars, this action activates the Callipers. Hydraulic or mechanical systems within the Callipers force the brake pads to clamp onto the spinning rotor. The contact between the brake pads and the rotor generates friction, converting the kinetic energy of the moving scooter or bicycle into thermal energy—heat—which is dissipated into the air. This friction reduces the rotation speed of the rotor and consequently slows down the wheel, bringing the vehicle to a stop or allowing it to slow as desired.

This braking method is favored for its reliability and efficiency, offering consistent performance and effective heat dissipation. It also provides substantial braking power without requiring excessive physical strength from the rider, making it ideal for both high-speed electric scooters and bicycles in various riding conditions. The design ensures that even in wet or dirty conditions, the braking remains relatively unaffected, unlike other braking systems where performance might degrade.

MATERIALS

For brake disks, a specific type of stainless steel that excels in terms of performance, corrosion resistance, and cost-effectiveness is the 304 stainless steel. This grade is highly regarded for its excellent mechanical properties and outstanding resistance to a wide range of atmospheric environments. 304 stainless steel contains a higher chromium and nickel content, which is crucial for enhancing its corrosion resistance. This makes it particularly resilient against rust and deterioration caused by exposure to moisture and road salts, a common issue in harsh weather conditions.

The thermal properties of 304 stainless steel are also favorable for brake disk applications. It efficiently conducts and dissipates heat generated during braking, which helps prevent warping or thermal degradation, thus maintaining consistent braking performance over extended periods. Although 304 stainless steel may carry a higher initial cost than materials like cast iron, its durability and the infrequency of required replacements make it a more cost-effective option over the lifespan of the brake disks.

Moreover, the ease of maintenance associated with 304 stainless steel—due to its non-corrosive nature—means that it requires less intensive care to remain in optimal condition. It does not necessitate frequent cleaning or protective treatments to maintain its integrity and performance. This combination of durability, efficiency in heat management, and low maintenance needs makes 304 stainless steel an excellent choice for brake disks, especially for bicycles and electric scooters used in diverse environmental settings.

For brake Callipers, the specific Aluminium alloy often favored for its superior combination of performance, cost-effectiveness, serviceability, and maintainability is the 6061-T6 Aluminium alloy. This alloy is widely chosen in the automotive and cycling industries for its exceptional strength-to-weight ratio, providing the necessary durability and rigidity required for effective braking without significantly increasing the overall weight of the vehicle.

The 6061-T6 alloy is treated through a process known as tempering and aging, which enhances its mechanical properties, making it highly resistant to stresses encountered during braking. This treatment also improves its corrosion resistance, which is crucial for maintaining the integrity and performance of the brake Callipers over time, even in harsh weather conditions. Additionally, Aluminium 6061-T6 is relatively easy to machine and weld, which allows for precision manufacturing of complex Callipers designs that can accommodate various brake systems and configurations.

From a cost perspective, while 6061-T6 may be more expensive than some other alloys, its durability and longevity offset the initial investment by reducing the need for frequent replacements and maintenance. This makes it a cost-effective choice for manufacturers aiming to offer high-quality, reliable brake systems. Its ease of maintenance also contributes to reduced service costs over the vehicle's lifespan, ensuring that it remains a popular choice for brake Callipers in both conventional bicycles and electric scooters.

Advantages of Stainless Steel 304 for disk

- **Corrosion Resistance:** 304 stainless steel has excellent corrosion resistance due to its high chromium and nickel content. It withstands exposure to a wide range of atmospheric, chemical, and watery environments, which is particularly beneficial for components like brake disks that are frequently exposed to harsh conditions.
- **Thermal Stability:** This material maintains its integrity and mechanical properties even under high temperatures, which is crucial for brake disks that experience significant thermal stress during operation.
- **Durability:** The robust nature of 304 stainless steel ensures that brake disks are less prone to wear and tear, contributing to longer service life and reduced replacement frequency.
- **Cost-Effectiveness:** While the initial cost might be higher compared to some other metals like cast iron, the longevity and minimal maintenance needs of 304 stainless steel disks make them more economical over the long term.
- **Low Maintenance:** The non-corrosive surface of 304 stainless steel does not require frequent cleaning or protective treatments, reducing the time and cost associated with maintenance.
- **Safety:** The consistent performance of 304 stainless steel in various environmental conditions ensures reliable braking, which is critical for safety in bicycles and electric scooters.
- **Aesthetic Appeal:** 304 stainless steel has a pleasing aesthetic and does not tarnish easily, maintaining its appearance over time, which is often considered in consumer products like bicycles and scooters.

Advantages of Aluminium 6061-T6 for Callipers

- **Weight Reduction**: Aluminium 6061-T6 is significantly lighter than other metals like steel, which helps reduce the overall weight of the vehicle, enhancing fuel efficiency and performance, especially in bicycles and electric scooters where weight is a critical factor.
- **High Strength-to-Weight Ratio**: Despite its light weight, 6061-T6 maintains a high level of strength and durability, making it ideal for the structural demands of brake Callipers.
- **Corrosion Resistance:** This alloy offers good resistance to corrosion, which is crucial for parts exposed to various environmental elements. It ensures longer lifespan and better performance under different weather conditions.
- **Thermal Conductivity:** Aluminium 6061-T6 has excellent thermal conductivity, which helps dissipate heat generated during braking more efficiently than some other materials, reducing the risk of overheating.
- **Machinability:** This alloy is relatively easy to machine, allowing for the precise fabrication of components like brake Callipers, which can have complex shapes and require tight tolerances.
- **Cost-Effectiveness:** While providing superior properties, Aluminium 6061-T6 is still cost-effective in terms of both initial material cost and lifecycle costs due to its durability and low maintenance requirements.
- **Flexibility in Manufacturing:** The alloy can be extruded, rolled, or forged, offering flexibility in manufacturing processes, which can help optimize the production of brake Callipers.
- **Anodizing Potential**: Aluminium 6061-T6 responds well to anodizing, a process that can further improve corrosion resistance and surface hardness, as well as allow for color customization, which can be appealing for consumer-facing applications.

MANUFACTURING PROCESS

The best manufacturing processes for brake disks made from Stainless Steel 304 and Callipers from Aluminium 6061-T6 involve a combination of advanced techniques tailored to the specific properties and demands of each material, optimizing performance, cost-effectiveness, serviceability, and maintainability.

For brake disks using Stainless Steel 304, the process typically starts with precision blanking. This method involves cutting the initial disk shape from large, flat sheets of stainless steel. Precision blanking is highly efficient and minimizes material waste, which is crucial given the higher cost of Stainless Steel 304. The blanked disks are then subjected to precision grinding, which ensures the surface is perfectly flat and achieves the necessary surface finish to enhance friction characteristics and braking performance. This step is vital for maintaining the flatness required to prevent vibrations and ensure uniform pad contact during braking.

After grinding, the disks undergo a polishing process to remove any surface imperfections and to enhance corrosion resistance—a critical step given the exposure of brake disks to harsh environmental conditions. The final process for the disks is usually a passivation treatment, which involves treating the steel with a citric or nitric acid solution to remove free iron from the surface, thereby enhancing its natural corrosion resistance without affecting the overall mechanical properties.

High-pressure die casting (HPDC) is an ideal manufacturing process for producing 100,000 units of brake Callipers made from Aluminium 6061-T6. This process offers numerous advantages that make it the most cost-effective and efficient choice for high-volume production of complex, near-net-shape components like brake Callipers.

In HPDC, molten Aluminium 6061-T6 is injected into a steel die cavity under high pressure, typically ranging from 1,000 to 5,000 psi (69 to 345 bar). The high pressure ensures that the molten metal fills the die cavity completely and solidifies quickly, resulting in parts with excellent dimensional accuracy, tight tolerances, and minimal shrinkage or warpage. This is crucial for brake Callipers, as they must fit and function properly within the brake system.

One of the key advantages of HPDC is its ability to produce parts with complex geometries and thin walls, which is essential for designing lightweight and high-performance brake Callipers. The process can incorporate intricate details, such as mounting points, fluid passages, and reinforcing ribs, into a single casting, reducing the need for additional assembly steps. This design flexibility allows for the optimization of the brake Callipers's strength, stiffness, and weight distribution.

Another significant benefit of HPDC is its high production rate. The process has very fast cycle times, typically ranging from a few seconds to a minute per part, depending on the size and complexity of the brake Callipers. This enables manufacturers to produce large quantities of Callipers quickly and efficiently, meeting the demands of high-volume production. The automated nature of HPDC also ensures consistent quality and repeatability across the entire production run.

HPDC is a near-net-shape process, meaning that the cast parts are close to their final shape and require minimal machining or finishing. This reduces material waste and post-processing costs compared to other manufacturing methods like machining from solid billets. The process also offers good material efficiency, as the high pressure helps to minimize porosity and ensure a dense, uniform microstructure in the cast part.

Tooling costs are another important consideration in high-volume production. While the initial cost of designing and fabricating the steel dies for HPDC can be high, the cost is spread out over the large production volume. As a result, the per-unit tooling cost for 100,000 brake Callipers is relatively low, making HPDC a cost-effective choice for high-volume production.

HPDC is well-suited for casting Aluminium 6061-T6, a popular choice for brake Callipers due to its excellent strength-to-weight ratio, corrosion resistance, and good machinability. The process can handle the high melting temperature of this alloy (around 650°C or 1200°F) and produce parts with good mechanical properties. After casting, the brake Callipers can undergo a T6 heat treatment to enhance their strength and hardness further.

Post-casting operations for HPDC brake Callipers may include machining of critical surfaces, such as mounting holes and piston bores, to achieve precise dimensions and a smooth surface finish. The Callipers may also receive surface treatments, such as anodizing or painting, to improve their corrosion resistance and appearance.

In conclusion, high-pressure die casting is the most cost-effective and efficient manufacturing process for producing 100,000 units of Aluminium 6061-T6 brake Callipers. The process offers high production rates, design flexibility, dimensional accuracy, material efficiency, and relatively low per-unit tooling costs, making it the ideal choice for this high-volume application.

Advantages of precision blanking

- **Superior Accuracy and Precision:** Precision blanking offers exceptional control over dimensions and tolerances, producing parts with high accuracy. This precision is essential for components like brake discs, where exact measurements are critical for proper alignment and function.

- **Cleaner Edges:** Unlike traditional cutting methods, precision blanking produces cleaner cuts with minimal burrs. This reduces the need for secondary finishing processes, saving time and reducing production costs.
- **Efficiency in Material Usage:** Precision blanking is known for minimizing material waste. This efficiency is especially important when using high-cost materials like stainless steel,

making the process more cost-effective compared to using less expensive materials like cast iron that may generate more waste.

- **Speed of Production:** The process is capable of high-speed production, allowing manufacturers to produce large volumes of brake discs quickly. This is advantageous for meeting large orders and maintaining consistent supply chains.
- **Tool Longevity:** The tools used in precision blanking undergo less wear and tear compared to those used in traditional forging or casting processes. This extends the lifespan of the tools and further reduces operational costs.
- **Reduced Post-Processing:** Due to the high-quality finish and dimensional accuracy obtained from precision blanking, extensive post-processing is often unnecessary. This contrasts with cast iron components that might require additional treatments to achieve a comparable surface quality.
- **Versatility in Material Selection:** While precision blanking is highly effective for stainless steel, it can also be adapted to various other materials, offering manufacturers flexibility in material choice without compromising on the output quality.
- **Maintains Material Integrity**: Precision blanking is a cold-working process, meaning it doesn't alter the microstructure of the metal as some heat-based processes can. This ensures that the mechanical properties of the metal, such as strength and corrosion resistance, remain intact.

Advantages of Die casting over other process

- **High production rates:** HPDC has very fast cycle times, ranging from seconds to minutes per part, making it the most efficient process for high-volume production of brake Callipers compared to low-pressure die casting, gravity die casting, sand casting, forging, and machining from billet.
- **Cost-effectiveness**: The high production rates, lower per-unit tooling costs, and reduced post-processing requirements make HPDC the most cost-effective choice for producing large quantities of brake Callipers compared to alternative processes.
- **Design flexibility:** HPDC can produce parts with complex geometries, thin walls, and intricate details, allowing for greater design flexibility in brake Calliper production compared to processes like gravity die casting and sand casting.
- **Dimensional accuracy and consistency:** The high pressure used in HPDC ensures excellent dimensional accuracy, tight tolerances, and minimal shrinkage or warpage, resulting in more consistent and precise brake Callipers compared to low-pressure die casting, sand casting, and forging.
- **Material efficiency:** HPDC is a near-net-shape process, producing parts that are close to their final shape and requiring minimal machining or finishing, thus reducing material waste compared to machining from billet.
- **Improved mechanical properties:** The high pressure in HPDC results in a denser and more uniform microstructure, leading to better mechanical properties in the cast brake Callipers compared to gravity die casting and sand casting.
- **Compatibility with Aluminium 6061-T6:** HPDC is well-suited for casting Aluminium 6061-T6, offering good mold filling, minimal porosity, and the ability to produce parts with good mechanical properties after heat treatment.
- **Reduced post-processing:** The near-net-shape capability, good surface finish, and minimal porosity of HPDC reduce the need for extensive post-processing, such as machining and surface treatment, compared to sand casting and forging, further reducing overall production costs and time.

Justifications for key dimensions that are used to reduce cost

- **Material Optimization:** A 14 cm diameter is compact, reducing the amount of stainless steel used without compromising the essential surface area needed for effective braking. This size is likely sufficient for the application's requirements while keeping material costs low.
- **Thickness Selection:** At 5 mm thickness, the disc strikes a balance between being robust enough to resist warping or excessive wear under heat and pressure, and thin enough to minimize material use. The selected thickness ensures durability while conserving material, reducing the overall cost.
- **Weight Considerations:** The dimensions and chosen materials contribute to a lighter brake system, which is crucial for bicycles and electric scooters where weight impacts overall performance and efficiency.
- **Thermal Management:** Stainless steel has good thermal conductivity, and the 5 mm thickness allows for adequate heat dissipation during braking. This reduces the likelihood of heat-related performance issues, maintaining the integrity of the brake disc over time and avoiding costly repairs or replacements.
- **Aluminium Callipers:** Using Aluminium 6061-T6 for the callipers is a cost-effective choice due to its lower price point compared to other high-performance alloys, and its lightweight nature reduces the inertia of the brake system, improving handling and reducing strain on the entire braking system.
- **Machinability and Manufacturability**: Both stainless steel for the disc and Aluminium 6061-T6 for the callipers are materials known for their excellent machinability. This allows for more complex design features (as seen in the calliper design in the image) to be manufactured without significantly increasing production costs.
- **Design Efficiency:** The disc features a series of cut-outs which serve to reduce weight and material costs while also contributing to better heat dissipation. The calliper design is compact and appears to have minimal excess material, which is aligned with the principles of material and cost efficiency.
- **Maintenance and Serviceability:** The simplicity of the disc design and the accessibility of the Callipers suggest that maintenance can be performed easily and at a lower cost. The commonality of the materials also means that replacement parts would be readily available and affordable.

DFA PRINCIPLE

- **Part Consolidation**: The Callipers design appears to consolidate multiple functions into single components. The Callipers body is a single piece that may incorporate features for pad retention, fluid channels, and mounting, reducing the number of parts and fasteners needed.
- **Simplified Assembly:** The brake pads may be consolidated into one larger pad per side instead of multiple smaller pads. This can simplify the assembly process, as fewer components need to be handled and positioned, reducing assembly time and potential errors.
- **Standardization of Components:** The calliper appears to use standardized fasteners and fittings for attachment, which simplifies manufacturing and assembly processes, as well as maintenance and service tasks.
- **Ease of Access and Serviceability:** The design shows sufficient space around the fastening and moving parts, which is beneficial for both assembly and maintenance, as it allows for easy access with tools for installation and servicing.
- **Symmetrical Design:** The Callipers’ design seems symmetrical, which can prevent incorrect assembly—parts can be assembled from either direction without concern for misorientation.

- **Self-Locating Features:** The interface between the disk and the Callipers seems to have self-locating features that aid in alignment during assembly. This reduces the time needed to position the parts correctly, facilitating faster and more reliable assembly.
- **Visual Simplicity:** The overall design has a visually simple and clean layout, which can reduce cognitive load during assembly, minimizing the chances of incorrect assembly and making the training process for assembly workers more straightforward.
- **Reduction in Adjustment:** The Callipers design does not seem to require significant adjustment or tuning once assembled, implying that precision in the manufacturing process allows for a 'fit and forget' assembly method, which is ideal for reducing production time and costs.

Part Cost Estimation

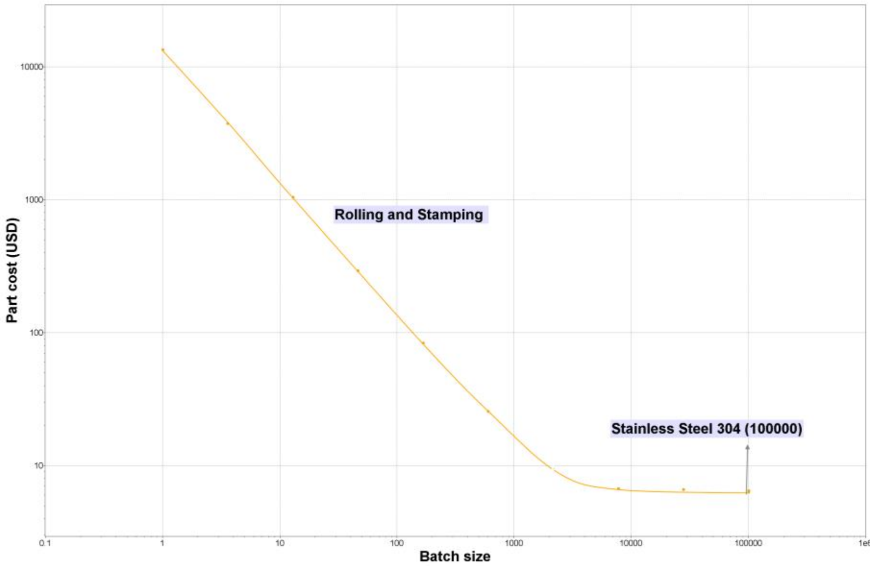


Figure 17: Brake Disc Part cost vs Batch Size

Part Cost Estimation

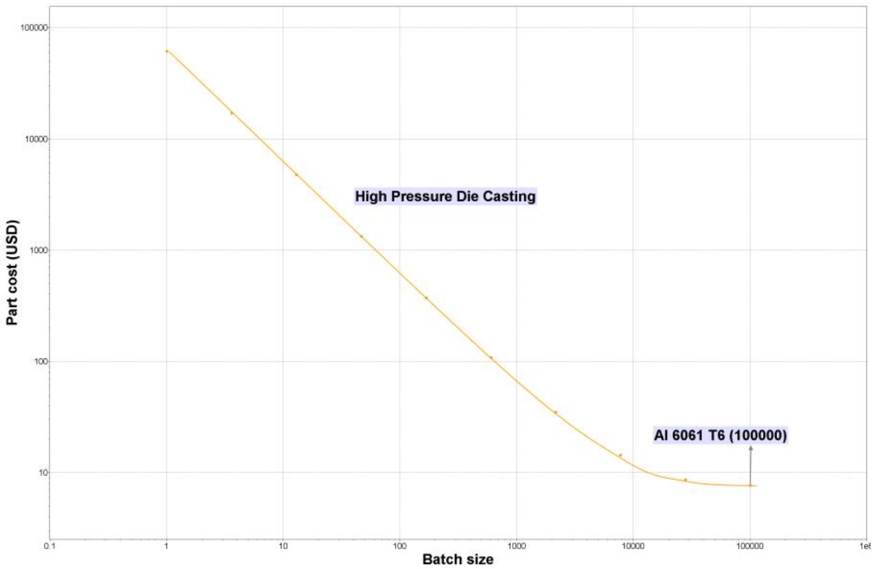


Figure 18: Brake Callipers Part cost vs Batch Size

The cost estimation process utilizing the Granta Edu pack involved a comprehensive analysis of several key factors influencing the production expenses of each part. These factors included considerations such as the material composition of the part, its shape complexity, and whether it underwent primary manufacturing processes, secondary processes, or a combination of both. Additionally, parameters such as the mass and length of the product, as well as the envelope volume it occupies, were taken into account to accurately gauge the manufacturing requirements.

Furthermore, specific details about the manufacturing processes employed, including any specialized techniques or equipment used, were factored into the cost estimation process. By considering these diverse elements, a thorough assessment of the production costs for each part was achieved.

Upon applying these parameters and analysing the batch size of 100,000 units, the estimated cost per part was determined to be $5.5 and $8.7 for brake disc and Brake callipers respectively. This figure represents the culmination of a detailed evaluation encompassing various facets of the manufacturing process, ultimately providing a comprehensive understanding of the cost implications associated with producing the specified quantity of parts.

2.8. HANDLEBAR AND HEIGHT ADJUSTMENT BAR

Working Principle

Figure 19: Handlebar and Height adjustment Bar

The handlebar and height adjustment system of an electric scooter is designed to provide a comfortable and adjustable riding position for users of different heights. The working principle of this system is based on a telescopic mechanism that allows the handlebar stem to be extended or retracted to the desired height. The handlebar itself is the primary interface between the rider and the scooter, providing a means to steer and control the vehicle. It is typically made from lightweight and strong materials, such as Aluminium alloys, to ensure durability and minimize weight. The handlebar is connected to the front fork of the scooter through the stem, which is a hollow tube that houses the height adjustment mechanism.

The height adjustment hollow bar, also known as the stem, is a telescopic tube that consists of two main parts: an outer tube (lower stem) and an inner tube (upper stem). The outer tube is fixed to the front fork, while the inner tube is connected to the handlebar. The inner tube can slide inside the outer tube, allowing for height adjustment. To secure the handlebar at the desired height, a clamping mechanism is used. This mechanism typically consists of a quick-release lever or a collar with bolts that can be tightened or loosened to adjust the clamping force. When the clamping mechanism is loosened, the inner tube can slide freely inside the outer tube, allowing the user to adjust the handlebar height. Once the desired height is achieved, the clamping mechanism is tightened, which applies pressure to the inner tube, preventing it from sliding and securely locking the handlebar in place.

To adjust the handlebar height, the user first loosens the clamping mechanism. The inner tube is then extended or retracted to the desired height by sliding it within the outer tube. Once the desired height is reached, the user tightens the clamping mechanism to lock the inner tube in place and secure the handlebar at the new height. To ensure safe operation, the telescopic stem often includes safety features such as minimum insertion marks or stops. These features prevent the inner tube from being extended too far, which could compromise the structural integrity of the stem. Additionally, the clamping mechanism must be designed to provide sufficient clamping force to prevent the handlebar from slipping or rotating during use.

In summary, the working principle of the handlebar and height adjustment system in electric scooters is based on a simple telescopic mechanism that allows users to easily adjust the handlebar height to their preferred riding position. This adjustability enhances comfort, control, and safety for riders of different heights. The use of lightweight and strong materials, such as Aluminium alloys, ensures that the handlebar and stem assembly is both durable and easy to manipulate.

MATERIAL

Aluminium 6061-T6 is an excellent choice for manufacturing the handlebar and height adjustment bar (stem) of an electric scooter due to its unique combination of properties. This Aluminium alloy is known for its high strength-to-weight ratio, excellent corrosion resistance, and good machinability, making it ideal for applications that require both durability and lightweight construction. The T6 temper designation indicates that the alloy has been solution heat-treated and artificially aged to achieve optimal strength and hardness, further enhancing its mechanical properties.

When used for the handlebar and stem of an electric scooter, Aluminium 6061-T6 offers several key benefits. First, its high strength-to-weight ratio allows for the creation of sturdy yet lightweight components, which is crucial for maintaining the overall portability and maneuverability of the scooter. The handlebar and stem must withstand the stresses and vibrations generated during riding, and Aluminium 6061-T6 provides the necessary strength and stiffness to ensure a safe and stable ride. Additionally, the alloy's excellent corrosion resistance helps to protect the handlebar and stem from weathering and degradation, even when exposed to harsh outdoor conditions or humid environments.

Another advantage of using Aluminium 6061-T6 for the handlebar and height adjustment bar is its good machinability. This property allows for precise and efficient manufacturing processes, such as extrusion, cutting, and drilling, which are necessary to create the telescopic mechanism and clamping system that enable height adjustability. The alloy can be easily extruded into the desired cross-sectional shapes for the outer and inner tubes of the stem, and machining operations can be performed to create the necessary features, such as holes for the clamping mechanism or threads for attaching the handlebar.

Furthermore, Aluminium 6061-T6 offers excellent weldability, which is important for assembling the handlebar and stem components. The alloy can be readily welded using various methods, such as TIG or MIG welding, to create strong and reliable joints between the handlebar, stem, and front fork. This ensures that the assembly can withstand the dynamic loads and stresses encountered during use, providing a durable and long-lasting height adjustment system.

In addition to its mechanical properties, Aluminium 6061-T6 also offers a clean and attractive appearance. The alloy can be easily polished, anodized, or painted to achieve the desired aesthetic finish, allowing manufacturers to create visually appealing and customizable handlebar and stem designs that complement the overall style of the electric scooter.

In summary, Aluminium 6061-T6 is an ideal material for manufacturing the handlebar and height adjustment bar of an electric scooter. Its high strength-to-weight ratio, excellent corrosion resistance, good machinability, and weldability make it well-suited for creating durable, lightweight, and adjustable components that enhance the performance, safety, and user experience of the scooter. The alloy's versatility and attractive appearance further contribute to its suitability for this application, making it a popular choice among electric scooter manufacturers.

Advantages of Aluminium over other materials

- **Lightweight:** Aluminium 6061 has a significantly lower density compared to cast iron and stainless steel, allowing for the creation of much lighter-weight components. This reduced weight is particularly beneficial for electric scooters, as it can improve overall vehicle performance, handling, and energy efficiency.
- **Strength-to-Weight Ratio:** Aluminium 6061 provides an excellent balance of strength and low weight. The alloy can be heat-treated to achieve high tensile and yield strengths, making it capable of withstanding the loads and stresses experienced by scooter handlebars and forks, while still remaining relatively lightweight.
- **Corrosion Resistance:** Aluminium 6061 exhibits good resistance to corrosion, thanks to the formation of a protective oxide layer on the surface. This characteristic helps to maintain the structural integrity and appearance of the components over time, even in outdoor environments with exposure to moisture, salt, and other corrosive elements.
- **Ease of Fabrication:** Aluminium 6061 is relatively easy to machine, weld, and form, simplifying the manufacturing process and reducing production costs. This also facilitates easier repair and modification of the components, if needed, during the scooter's lifetime.
- **Cost-Effectiveness:** Compared to premium materials like titanium, Aluminium 6061 is a more cost-effective solution for electric scooter manufacturers, allowing them to balance performance and affordability for their products.
- **Thermal Conductivity:** Aluminium 6061 has a higher thermal conductivity compared to cast iron and stainless steel, which can be beneficial for dissipating heat generated by the electric motor or braking system, potentially improving the overall thermal management of the scooter.
- **Recyclability:** Aluminium is highly recyclable, making it a more environmentally-friendly choice compared to some other metals. This can contribute to the overall sustainability of the electric scooter's lifecycle.

PROCESS

The extrusion process is a highly efficient and cost-effective method for manufacturing the handlebar and height adjustment hollow bar (stem) of 100,000 units of electric scooters using Aluminium 6061-T6. Extrusion is a process in which a preheated billet of Aluminium is forced through a steel die with a specific cross-sectional shape, creating long, continuous profiles with a constant cross-section. This process is particularly well-suited for producing the handlebar and stem components, as it allows for the creation of complex, hollow profiles with high dimensional accuracy and consistency.

To begin the extrusion process, Aluminium 6061-T6 billets are preheated to a temperature between 400°C and 500°C (750°F to 930°F). This preheating stage is essential for making the material more malleable and easier to extrude, as it reduces the force required to push the billet through the die and helps to prevent cracking or tearing during the extrusion process. Once heated, the billet is loaded into the extrusion press, which consists of a hydraulic ram and a steel die with the desired cross-sectional shape of the handlebar or stem.

The hydraulic ram applies an immense force to the preheated billet, pushing it through the die opening. As the Aluminium is forced through the die, it plastically deforms and takes on the shape of the die cavity, creating a long, continuous profile with a uniform cross-section. The extrusion speed and pressure are carefully controlled to ensure that the Aluminium flows smoothly through the die and maintains the desired shape and dimensions.

After exiting the die, the extruded profile is cooled, typically using air or water, to help maintain its shape and mechanical properties. The cooling process also helps to prevent warping or distortion of the profile, ensuring that the handlebar and stem components remain straight and true.

Once cooled, the extruded profiles are cut to the desired lengths for the handlebar and stem using saws or other cutting tools. The cutting process is optimized to minimize material waste and ensure that each component meets the specified length tolerances.

Following the cutting stage, the extruded components undergo a T6 heat treatment process to enhance their mechanical properties. The T6 heat treatment involves solution heat treating, quenching, and artificial aging, which increases the strength, hardness, and corrosion resistance of the Aluminium 6061 alloy. This heat treatment process is crucial for ensuring that the handlebar and stem components can withstand the stresses and loads encountered during use, providing a durable and long-lasting height adjustment system for the electric scooter.

Finally, any necessary finishing operations, such as machining, anodizing, or painting, are performed on the extruded components to achieve the desired appearance and functionality. These finishing steps may include drilling holes for the clamping mechanism, tapping threads for attaching the handlebar, or applying a protective coating to enhance corrosion resistance and aesthetics.

By using the extrusion process to manufacture the handlebar and height adjustment hollow bar for 100,000 units of electric scooters, manufacturers can achieve high production efficiency, consistent quality, and cost-effectiveness. The ability to produce long, continuous profiles with complex cross-sections in a single operation reduces the need for additional manufacturing steps and minimizes material waste. Additionally, the extrusion process enables the creation of lightweight, strong, and durable components that are essential for the performance and safety of the electric scooter.

Advantages of CNC Machining Process over other process

- The extrusion process is a highly efficient and cost-effective method for manufacturing the handlebar and height adjustment hollow bar (stem) of 100,000 units of electric scooters using Aluminium 6061-T6. Extrusion is a process in which a preheated billet of Aluminium is forced through a steel die with a specific cross-sectional shape, creating long, continuous profiles with a constant cross-section. This process is particularly well-suited for producing the handlebar and stem components, as it allows for the creation of complex, hollow profiles with high dimensional accuracy and consistency.

- To begin the extrusion process, Aluminium 6061-T6 billets are preheated to a temperature between 400°C and 500°C (750°F to 930°F). This preheating stage is essential for making the material more malleable and easier to extrude, as it reduces the force required to push the billet through the die and helps to prevent cracking or tearing during the extrusion process. Once heated, the billet is loaded into the extrusion press, which consists of a hydraulic ram and a steel die with the desired cross-sectional shape of the handlebar or stem.

- The hydraulic ram applies an immense force to the preheated billet, pushing it through the die opening. As the Aluminium is forced through the die, it plastically deforms and takes on the shape of the die cavity, creating a long, continuous profile with a uniform cross-section. The extrusion speed and pressure are carefully controlled to ensure the Aluminium flows smoothly through the die and maintains the desired shape and dimensions.

- After exiting the die, the extruded profile is cooled, typically using air or water, to help maintain its shape and mechanical properties. The cooling process also helps prevent the profile's warping or distortion, ensuring that the handlebar and stem components remain straight and true.
- Once cooled, the extruded profiles are cut to the desired lengths for the handlebar and stem using saws or other cutting tools. The cutting process is optimized to minimize material waste and ensure that each component meets the specified length tolerances.
- Following the cutting stage, the extruded components undergo a T6 heat treatment process to enhance their mechanical properties. The T6 heat treatment involves solution heat treating, quenching, and artificial aging, which increases the strength, hardness, and corrosion resistance of the Aluminium 6061 alloy. This heat treatment process ensures that the handlebar and stem components can withstand the stresses and loads encountered during use, providing a durable and long-lasting height adjustment system for the electric scooter.
- Finally, any necessary finishing operations, such as machining, anodizing, or painting, are performed on the extruded components to achieve the desired appearance and functionality. These finishing steps may include drilling holes for the clamping mechanism, tapping threads for attaching the handlebar, or applying a protective coating to enhance corrosion resistance and aesthetics.
- By using the extrusion process to manufacture the handlebar and height adjustment hollow bar for 100,000 units of electric scooters, manufacturers can achieve high production efficiency, consistent quality, and cost-effectiveness. The ability to produce long, continuous profiles with complex cross-sections in a single operation reduces the need for additional manufacturing steps and minimizes material waste. Additionally, the extrusion process enables the creation of lightweight, strong, and durable components that are essential for the performance and safety of the electric scooter.

Justifications for key dimensions that are used to reduce cost

- **Handlebar Length**: The handlebar length of 40 cm is a suitable size that provides good control and manoeuvrability for the rider, without being excessively long which would increase material usage and weight.
- **Handlebar Diameter**: The handlebar diameter of approximately 2 cm is a common and ergonomic size that allows for a comfortable grip, while not requiring excessive material.
- **Hollow Cross-Section**: The handlebar and fork seem to have a hollow, tubular cross-section, which allows for a favorable strength-to-weight ratio by using the material more efficiently compared to a solid cross-section.
- **Minimal Ornamentation:** The design appears to be relatively simple, without any unnecessary decorative features or complex geometries that could increase material consumption and manufacturing costs.
- **Recycled Aluminium:** Utilizing recycled Aluminium 6061 material can help reduce the raw material costs while still maintaining the desired mechanical properties.
- **Uniform Wall Thickness:** The handlebar and fork appear to have a consistent wall thickness throughout their design. This allows for efficient material usage and simplifies the CNC machining process.
- **Minimal Machining Complexity:** The overall shape of the handlebar and fork is relatively simple, featuring straight sections and gentle curves. This reduces the complexity of the CNC machining operations, which can lower manufacturing costs.
- **Stress Relief Features:** The image shows small chamfers or fillets at the transitions between the handlebar/fork and their connecting points. These stress relief features help distribute loads more evenly, potentially allowing for the use of thinner wall sections without compromising strength.
- **Integrated Clamping Mechanism:** The handlebar design incorporates a clamping mechanism, likely to secure it to the scooter's steering column. This integrated approach eliminates the need for additional hardware, saving material and assembly costs.

DFA PRINCIPLE

- **Simplicity and Standardization:** The design uses a minimal number of components and standard cross-sections, reducing manufacturing complexity and costs.
- **Ease of Assembly and Modularity**: The telescopic design allows for easy assembly and adjustment, with modular components that simplify maintenance and repair.
- **Minimal Secondary Operations:** The extruded profiles minimize the need for additional machining or drilling, reducing manufacturing time and costs.
- Material Selection: Aluminium 6061-T6 provides the necessary strength and lightweight properties, making it well-suited for the extrusion process and the application.
- **Hollow Tube Structure**: The hollow tube design reduces weight, optimizes strength-to-weight ratio, and promotes cost-effectiveness by minimizing material usage.
- **Slotted Fit:** The slotted fit enables easy assembly and secure adjustment of the height without requiring complex alignment or fastening methods, simplifying the manufacturing process.
- **Optimized Geometry:** The cross-sectional shape is optimized to provide the necessary strength and stiffness while minimizing material usage, reducing weight and cost.
- **Design for Adjustability:** The telescopic design incorporates adjustability as a key feature, allowing the scooter to accommodate users of different heights without requiring additional components or complex mechanisms.

Part cost Estimator

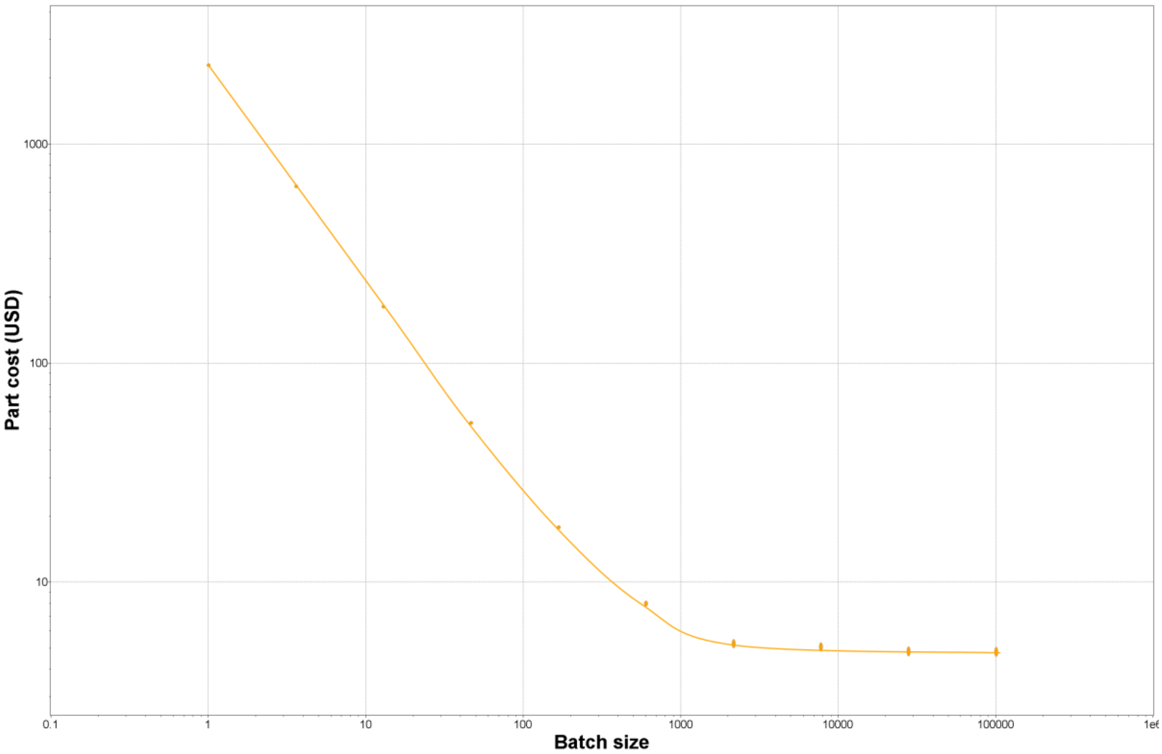


Figure 20: Handlebar Part Cost vs Batch Size

Machining Cost

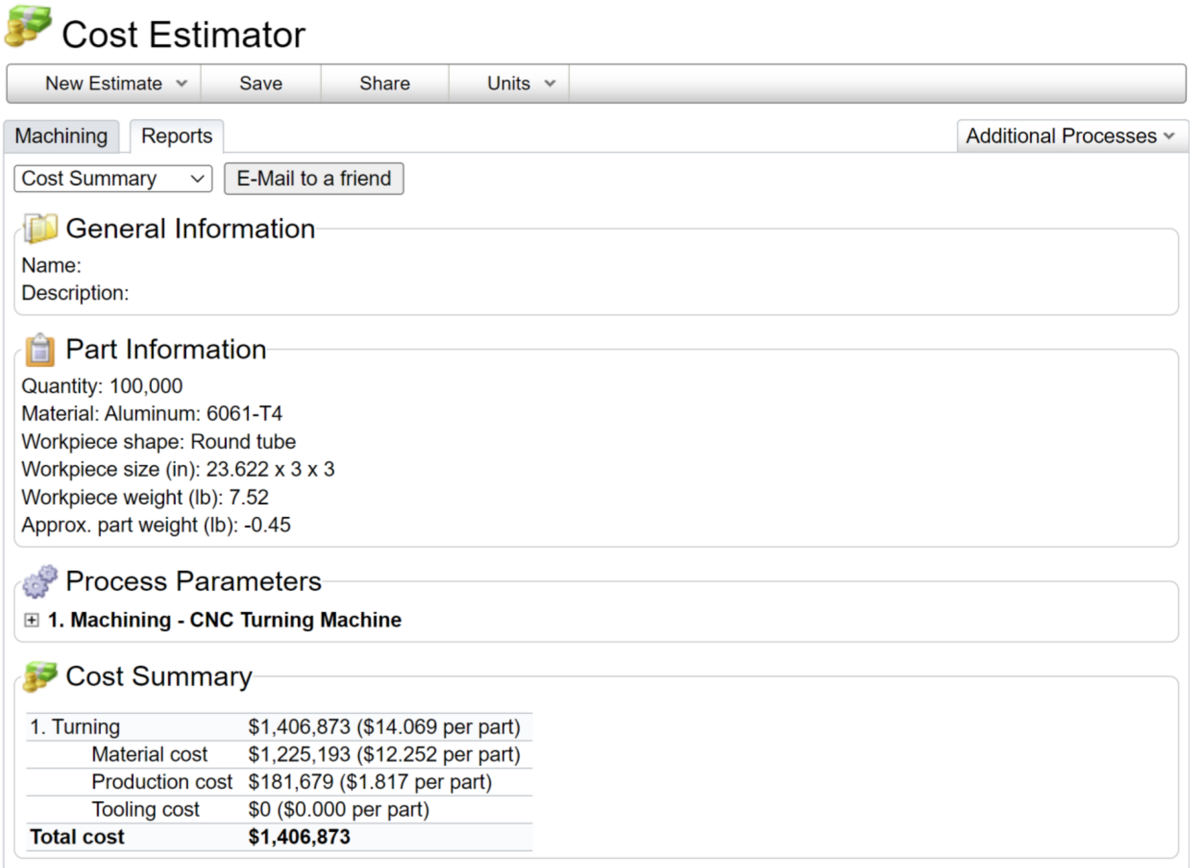


Figure 21: Machining Cost

The cost estimation process utilizing the Granta Edu pack involved a comprehensive analysis of several key factors influencing the production expenses of each part. These factors included considerations such as the material composition of the part, its shape complexity, and whether it underwent primary manufacturing processes, secondary processes, or a combination of both. Additionally, parameters such as the mass and length of the product and the envelope volume it occupies were taken into account to gauge the manufacturing requirements accurately.

Furthermore, details about the manufacturing processes employed, including any specialized techniques or equipment used, were factored into the cost estimation process. Considering these diverse elements, a thorough assessment of the production costs for each part was achieved.

Upon applying these parameters and analysing the batch size of 100,000 units, the estimated cost per part was determined to be $ 4.7 / per part with extrusion and $14.3 /per part for turning and drilling (Machining) . This figure represents the culmination of a detailed evaluation encompassing various facets of the manufacturing process, ultimately providing a comprehensive understanding of the cost implications of producing the specified quantity of parts.

2.9. WHEEL FORK

Figure 22: Wheel Fork

The fork of an electric scooter is a crucial component designed to support the front wheel and facilitate steering, much like forks in bicycles and motorcycles. Comprising two parallel arms, known as tines or legs, the fork holds the front wheel axle at its base and connects to the scooter’s frame and steering handle at the top via the stem. This connection allows the rider to control the direction by rotating the handlebars, which pivot the fork. Forks are typically constructed from materials such as steel, Aluminium, or carbon fiber, chosen for their balance of strength, durability, and lightness, which influences the scooter's handling and overall weight.

Many electric scooters incorporate a suspension system within the fork to improve comfort and handling over uneven surfaces. This suspension may consist of springs, air, or hydraulic dampers that allow the fork legs to move vertically, absorbing shocks from the road. Such systems often include a damping mechanism to control the movement's speed, enhancing stability and preventing excessive bouncing. The amount of movement, known as 'travel,' varies with the fork design—greater travel can handle more significant shocks, making it suitable for rougher terrains, while less travel suits smoother surfaces.

Adjustability features in higher-end models allow riders to modify suspension stiffness and damping to suit personal preferences and road conditions. Depending on the design, forks also accommodate front-end components like braking systems, with mounts for disc or rim brakes. The shape and design of the fork can also impact the scooter’s aerodynamics, affecting speed and battery efficiency. Regular maintenance is vital for safety, ensuring the fork's integrity and functionality to prevent control loss, highlighting its role in performance and rider safety.

Material

Aluminium 6061-T6 is a widely appreciated material in manufacturing scooter forks due to its outstanding blend of strength, ductility, corrosion resistance, and ease of fabrication. This specific grade of Aluminium alloy is known for its engineering versatility and is particularly favoured in applications requiring lightweight yet durable components. The 'T6' in its designation refers to the temper or heat treatment process it undergoes, which significantly enhances its mechanical properties.

The alloy composition of 6061 includes magnesium and silicon, which contribute to its ability to be heat treated, thereby increasing its toughness and resistance to wear — qualities that are essential for the structural demands placed on scooter forks. These forks must not only support the weight of the scooter and rider but also absorb and withstand the dynamic forces of varied terrains and sudden impacts. The fatigue strength of Aluminium 6061-T6 ensures that the forks can endure repeated loading and unloading without failing.

Additionally, Aluminium 6061-T6 is favored for its weldability compared to other high-strength Aluminium alloys, which is crucial in manufacturing processes where different sections of the fork need to be joined securely. Its ability to undergo various fabrication processes including extrusion, forging, and machining also makes it highly adaptable to bespoke scooter designs.

Moreover, this material is corrosion-resistant, an important characteristic for scooters used in diverse environmental conditions, from urban settings to coastal areas where salt air might otherwise hasten degradation. Its surface accepts anodic coatings well, which not only further increases its corrosion resistance but also allows for a variety of cosmetic finishes — a vital aspect in consumer products like electric scooters, where aesthetics can play a significant role in consumer appeal.

The thermal conductivity of Aluminium 6061-T6 also plays a subtle yet important role in its use in scooter forks. It helps dissipate heat generated from the friction of the moving parts and braking systems, contributing to the overall safety and longevity of the scooter. Additionally, despite its robustness, Aluminium 6061-T6 is remarkably lightweight, which helps keep the scooter's overall weight down, improving handling and efficiency, and enhancing the ease of transport and manoeuvrability.

In conclusion, Aluminium 6061-T6 stands out as an exemplary choice for the manufacturing of scooter forks, bringing together a suite of properties that are ideally suited to the performance demands and environmental conditions faced by modern electric scooters. Its use in this application underscores a careful balance of engineering requirements and consumer needs, exemplifying its role in advancing scooter technology.

Advantages of Aluminium 6061 T6

- **Strength-to-Weight Ratio:** Aluminium 6061-T6 provides an excellent strength-to-weight ratio. This makes it ideal for use in applications where reducing weight without compromising strength is crucial, such as in transportation and aerospace industries.
- **Corrosion Resistance:** This alloy offers good resistance to corrosion from both atmospheric conditions and chemical exposure, which is beneficial for outdoor applications like scooter forks that are exposed to various environmental elements.
- **Weldability:** Aluminium 6061-T6 is known for its weldability compared to other high-strength Aluminium alloys. This characteristic is vital for manufacturing complex assemblies, allowing for strong, durable welds that maintain the integrity of the design.
- **Machinability:** Although not as easy to machine as softer Aluminium alloys, 6061-T6 still offers acceptable machinability, which is an advantage for producing precision parts where complex shapes or tight tolerances are required.
- **Formability:** In the T6 temper, 6061 Aluminium maintains a balance of formability and strength. It can be extruded or forged into complex shapes, making it a good choice for the geometrically complex structures of forks.
- **Anodizing and Other Finishes: The** alloy reacts well to surface treatments such as anodizing, which can enhance its surface hardness and appearance, providing additional resistance to wear and corrosion while allowing for color customization.
- **Thermal Conductivity:** Aluminium 6061 has excellent thermal conductivity, which can be beneficial in applications where heat dissipation is necessary, such as in mechanical parts subject to frictional heat.
- **Cost-Effectiveness:** While offering these mechanical and physical benefits, Aluminium 6061-T6 remains cost-effective compared to other materials with similar properties, such as carbon fibre or

some titanium alloys. This makes it a popular choice for various applications, balancing performance and cost.

Process

Die casting is a highly efficient manufacturing process used to produce complex metal parts, and it is particularly well-suited for creating forks for electric scooters using Aluminium 6061-T6. This method involves melting the Aluminium alloy and injecting it under high pressure into a precision-engineered steel mold or die. The high pressure ensures that the molten metal fills all intricate details of the mold, capturing complex geometries with a high level of accuracy. One of the key advantages of die casting is its ability to achieve excellent surface finishes and tight dimensional tolerances directly from the mold, reducing the need for additional machining. The rapid cooling and solidification that occurs as the metal enters the die not only helps in achieving these precise details but also enhances the mechanical properties of the Aluminium. Aluminium 6061-T6, known for its strength, toughness, and corrosion resistance, can be a bit challenging to cast due to its susceptibility to hot tearing. However, advancements in die casting technologies and techniques have improved the ability to cast this alloy successfully. This makes die casting a cost-effective choice for high-volume production of scooter forks, offering both durability and consistency essential for such critical components.

Advantages of die casting

- **High Production Efficiency:** Die casting is well-suited for high-volume production runs due to its ability to produce complex shapes with high repeatability and quick cycle times. This efficiency reduces production time and costs significantly.
- **Excellent Dimensional Accuracy:** The die-casting process offers superior dimensional accuracy and stability, producing consistent and uniform parts. This precision is crucial for components like forks that require fitting into precise mechanical assemblies.
- **Complex Geometries:** Die casting allows for creating complex part designs that would be difficult or impossible to achieve with other manufacturing processes. This includes thin walls, intricate contours, and detailed surface textures.
- **Reduced Assembly Operations:** Since die casting can produce complex shapes, it often reduces the need for additional assembly operations. Features like bosses, holes, and studs can be cast into the part directly, eliminating secondary operations and assembly steps.
- **Smooth Surface Finishes:** Parts produced by die casting typically have a smooth surface finish right out of the mold, which is ideal for cosmetic surfaces and can minimize the need for additional surface finishing processes.
- **Strength and Weight:** Die-cast parts are robust due to the dense microstructure obtained under high-pressure casting. This strength does not compromise the lightweight characteristics of materials like Aluminium, which is particularly important for components such as scooter forks that benefit from being light yet strong.
- **Tight Tolerance Capability:** The process offers excellent control over part dimensions, achieving tight tolerances often crucial in complex assemblies like those in automotive and aerospace applications.
- **Cost-Effective for Large Production Runs:** While the initial setup costs for die-casting molds and equipment can be high, the per-part cost is significantly reduced on large production runs. This makes die casting economically viable for manufacturing thousands to millions of parts.

Justifications for key dimensions that are used to reduce cost

- **Material Efficiency:** Aluminium 6061-T6 is chosen for its strength-to-weight ratio, machinability, and weldability, making it a cost-efficient material that reduces the need for extensive machining and has lower energy requirements in die casting.

- **Design Optimization**: A compact design featuring a short height rod (32 cm x 5 cm x 3 cm) minimizes material usage and waste while contributing to reduced machining time and energy consumption during manufacturing.
- **Cost-Effective Production:** Utilizing die casting for manufacturing exploits the material's suitability for the process and leverages economies of scale, significantly decreasing the cost per unit for high-volume production.
- **Minimized Post-Processing:** The precision of die casting allows for the production of near-net-shape parts, which reduces or eliminates the need for secondary machining, further lowering labor and equipment expenses.
- **Rapid Manufacturing:** Die casting's quick cycle time accelerates production rates, compared to other methods like forging, enhancing throughput and cost-effectiveness.
- **Reduced Logistics Costs:** The lightweight and compact nature of the part cuts down on shipping and handling costs, due to the reduced weight and space required for transport.
- **Production Consistency:** High dimensional accuracy from the die casting process minimizes the need for adjustments during assembly, saving on costs related to quality control and rework.
- **Extended Tooling Durability:** The die casting tools have a long lifespan, which spreads the tooling cost across a larger number of parts, further reducing the overall production cost of each unit.

DFA principle

- **Simplicity and Symmetry**: The fork has been designed with two attachments that are symmetrical. This can aid in manufacturing by allowing the use of the same tooling for both sides, thus reducing complexity and cost. Symmetry also tends to distribute stress more evenly, potentially increasing the durability of the part.
- **Modularity:** The presence of multiple holes for the pin to adjust the height of the scooter suggests a modular design. This modularity allows for customization and adaptability without needing different parts for different height settings, reducing manufacturing and inventory costs.
- **Standardization:** Utilizing a pin that can fit into any of the holes indicates the use of standardized parts. Standardization is a key DFMA principle as it simplifies both the manufacturing process and assembly, and it can also simplify maintenance and repair.
- **Ease of Assembly:** By designing the fork with features that make it easy to attach to the wheel and adjust the scooter's height, the assembly process is likely streamlined, which can reduce assembly time and cost.
- **Reduced Part Count:** Having a fork with two symmetrical attachments rather than multiple parts for each side reduces the overall part count. This simplification not only makes the assembly process faster but also minimizes the risks of assembly errors, inventory management complexities, and maintenance difficulties.
- **Integrated Functions:** The fork appears to serve multiple functions; it acts as a structural member, an attachment point for the wheel, and an adjustable mechanism for the scooter's height. Integrating multiple functions into a single part can reduce the need for additional components, thus streamlining both the manufacturing process and the assembly.
- **Error Proofing (Poka-yoke):** The design of the holes for the height adjustment pin may include some form of error-proofing. This could mean that the pin can only be inserted in the correct orientation, or there are features that make it clear to the assembler how the fork should be positioned, reducing the risk of incorrect assembly.
- **Material Selection**: Aluminium 6061-T6 is a common choice for many manufacturing applications due to its good strength-to-weight ratio, corrosion resistance, and weldability. This material is also well-suited for the die-casting process, which aligns with the DFMA principle of selecting materials that are appropriate for the intended manufacturing processes and end-use requirements.

- **Die Casting Compatibility:** The design of the fork must be compatible with the die casting process. This includes considerations like draft angles, wall thickness, and the inclusion of features that can be easily created by a die without the need for intricate machining post-casting. The fork's geometry should be designed to avoid undercuts and allow for smooth ejection from the die.
- **Thermal Considerations:** Aluminium 6061-T6 has good thermal properties which should be taken into account during the die casting process. The design might include considerations for even cooling and solidification to prevent warping or internal stresses that could weaken the part.
- **Surface Finish and Aesthetics:** Die casting can provide a good surface finish which is aesthetically pleasing and may eliminate the need for additional surface treatment processes. This not only affects the appearance but can also provide a protective layer against.

Part Cost Estimator

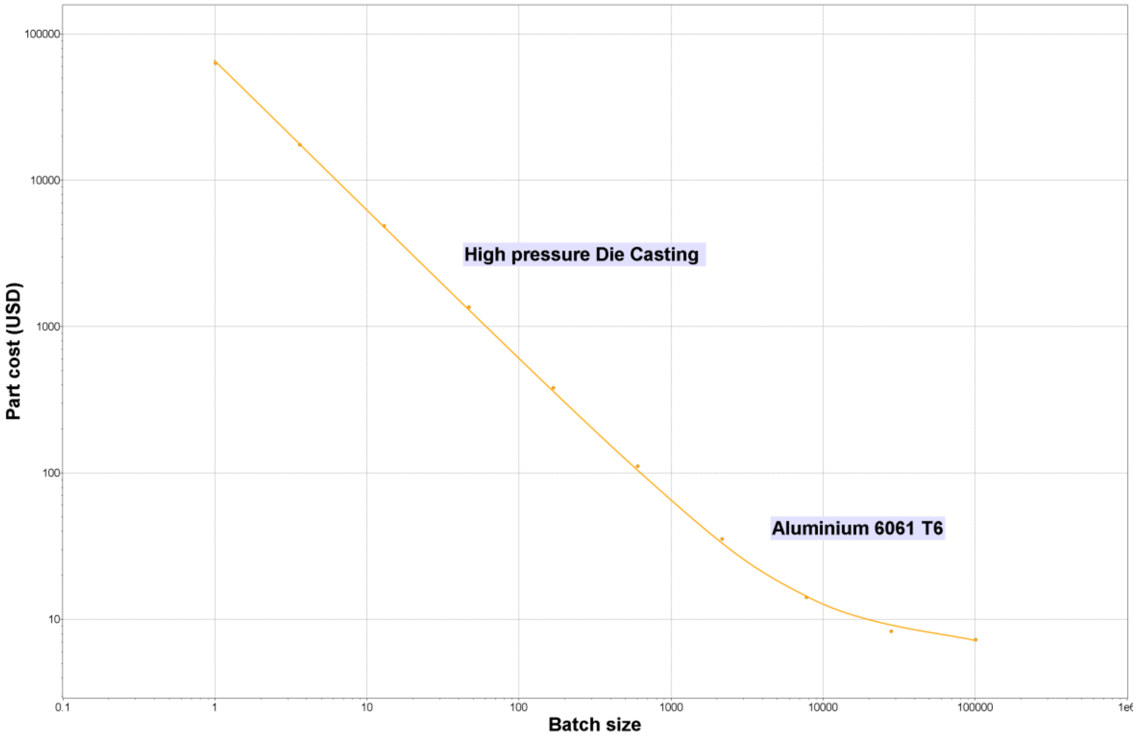


Figure 23: Fork Part Cost vs Batch Size

The cost estimation process utilizing the Granta Edu pack involved a comprehensive analysis of several key factors influencing the production expenses of each part. These factors included considerations such as the material composition of the part, its shape complexity, and whether it underwent primary manufacturing processes, secondary processes, or a combination of both. Additionally, parameters such as the mass and length of the product, as well as the envelope volume it occupies, were taken into account to accurately gauge the manufacturing requirements.

Furthermore, specific details about the manufacturing processes employed, including any specialized techniques or equipment used, were factored into the cost estimation process. By considering these diverse elements, a thorough assessment of the production costs for each part was achieved.

Upon applying these parameters and analysing the batch size of 100,000 units, the estimated cost per part was determined to be $ 7.5 for Forks. This figure represents the culmination of a detailed evaluation encompassing various facets of the manufacturing process, ultimately providing a comprehensive understanding of the cost implications associated with producing the specified quantity of parts.

2.10. Tires:

Figure 24: Electric Scooter Tires [5]

Estimated Pre-List Price 6 Dollars (For calculation purposes of this project, the Manufacturing price was kept at 8 dollars per tire, excluding costs relating to transportation and storage

Diameter: ID: 8.5 inches; OD: 10 Inches

Material: Natural Rubber

Manufacturing Process: Solid tires are made from natural and synthetic rubber and additives like sulfur, carbon black, and plasticizers. These components are carefully measured and mixed to create a compound with the desired properties, such as durability, elasticity, and resistance to wear. The manufacturing process - Initially, a blend of natural and synthetic rubber combined with reinforcing fillers is prepared. This compound is placed into a specially designed mold that shapes the tire and imprints the hole pattern. Undergoes vulcanization, where heat and pressure initiate a chemical reaction, cross-linking the rubber molecules to enhance elasticity and strength. After cooling, the tire is extracted from the mold, excess material is trimmed, and it undergoes a thorough inspection to ensure it meets quality standards before being deemed ready for use.

2.11. Front Wheel:

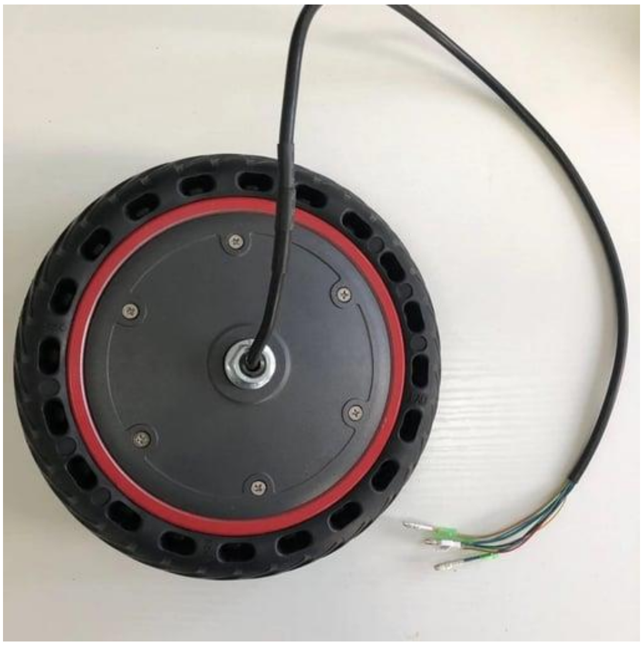


Figure 25: Electric Scooter Front Wheel containing the motor. [6]

Estimated Pre-List Price: $30

Diameter: ID: 8.5 inches; OD: 10 Inc

3. COST ANALYSIS FOR NON-STANDARDIZED PARTS AND ASSEMBLY

Assembly is a crucial stage in producing electric scooters, directly impacting the final product's efficiency, cost-effectiveness, and quality. In the case of manual assembly, the assembly time for an electric scooter consists of two primary elements: handling time and insertion time. Understanding and optimizing these components is essential for manufacturers seeking to streamline their manual assembly processes and remain competitive.

Handling time refers to the duration required for a human operator to pick up, orient, and position the various components of the electric scooter before the actual assembly takes place. This includes retrieving parts from storage bins, aligning them correctly, and preparing them for insertion. Efficient handling is crucial to minimize overall assembly time and reduce the risk of errors or damage to the components. Factors that can influence handling time include the workspace layout, the organization of parts and tools, and the ergonomics of the workstation.

On the other hand, insertion time is the time the human operator takes to join the components together to form the final product physically. This involves tasks such as screwing, bolting, welding, or snapping parts together, depending on the specific design of the electric scooter. Insertion time can be affected by factors such as the complexity of the components, the number of fasteners required, and the level of precision needed to ensure a secure and stable connection. The choice of assembly methods and tools can also play a significant role in determining insertion time.

To accurately estimate the assembly cost of an electric scooter in a manual assembly process, manufacturers often rely on the principles of product design for manufacturing and assembly (DFMA), as developed by Boothroyd and Dewhurst. DFMA is a systematic approach that aims to simplify product design and optimize manufacturing processes, ultimately reducing assembly time and cost. By applying DFMA principles, designers can identify and eliminate unnecessary components, standardize parts, and optimize the assembly sequence, resulting in a more efficient and cost-effective manual assembly process.

The Boothroyd Dewhurst method of assembly cost estimation involves a detailed product design analysis, considering factors such as part count, part complexity, insertion difficulty, and handling requirements. This analysis helps manufacturers identify areas where manual assembly time and cost can be reduced, such as by eliminating redundant parts, improving part accessibility, or redesigning components for easier handling and insertion by human operators.

To optimize the manual assembly process and minimize the total assembly time, manufacturers often employ various strategies and techniques alongside DFMA principles. One approach is to focus on ergonomic workstation design, which involves arranging the workspace to minimize unnecessary movement and facilitate efficient handling and insertion of components by human operators. This can include the use of adjustable workbenches, specialized jigs, and fixtures, and positioned parts bins.

Another strategy is to standardize parts across different models of electric scooters, reducing the variety of components that need to be handled and inserted by human operators. This simplifies the manual assembly process and increases efficiency as operators become more familiar with the standardized parts and procedures. Additionally, standardization can lead to cost savings through bulk purchasing and reduced inventory requirements.

Lean manufacturing principles, such as just-in-time (JIT) inventory management and continuous improvement, can also be applied to streamline the manual assembly process. JIT involves coordinating the delivery of components to the assembly line in precise quantities and at the exact time they are needed, reducing the need for extensive inventory storage and handling. Continuous improvement, on the other hand, encourages the ongoing identification and elimination of waste in the manual assembly process, leading to incremental gains in efficiency over time.

Finally, investing in training and skill development for human assembly operators is essential to ensure they have the necessary knowledge and abilities to perform their tasks efficiently and accurately. This can include training on proper handling techniques, using assembly tools and equipment, and identifying and resolving common assembly issues. Manufacturers can further optimize manual assembly time and improve overall product quality by fostering a skilled and motivated workforce.

In conclusion, optimizing manual assembly time is a critical concern for electric scooter manufacturers seeking to improve their production processes and remain competitive in the market. By understanding and addressing the key components of manual assembly time, namely handling time and insertion time, and applying the principles of product design for manufacturing and assembly (DFMA) as developed by Boothroyd and Dewhurst, manufacturers can employ various strategies to streamline their manual assembly operations. These include ergonomic workstation design, parts standardization, lean manufacturing principles, and operator training. By effectively implementing these approaches and using DFMA for assembly cost estimation, manufacturers can reduce manual assembly time, increase productivity, and ultimately deliver high-quality electric scooters to their customers.

Table 1: Part Estimations

Handling	Part Name	Insertion Time (s)	Handling Time (s)	Part Cost
1.	Deck	10.5	1.84	$25.892
2.	Mudguard	2 X 5.5	2.25	$6.75 X 2
3.	Stand	5.5	1.95	$0.88
4.	ABS Gripper	2 X 2.5	1.5	$1.137 X 2
5.	Rear Wheel Rim	7	1.13 X 2	$5.466
6.	Tires	6 X 2	1.13 X 2	$8 X 2
7.	Brake Lever	5	1.13	$4.2
8.	Disc	9	1.8	$5.5
9.	Brake Calliper	9	1.95	$8.7
10.	Handlebar	3.5	2.73	$18.9
11.	Fork	6	2.73	$9.5
12.	Battery	8	2.25	$40
13.	M4 Screw (Standard)	152	34.2	$4.7
14.	Front Rim with Motor	8	1.84	$30
Total	**Total Assembly**	**258**	**64.84**	**$183.12**

➢ Assembly Cost Estimation

The total assembly time for an electric scooter, which is a crucial factor in determining the overall production cost and efficiency, is calculated by summing up the insertion time and handling time. In this case, the total assembly time is 322.82 seconds, or approximately 5 minutes and 23 seconds. This time accounts for the manual assembly process, where human operators physically handle and join the various components of the scooter. In addition to the assembly time, inspection time is another important consideration. Based on market and literature surveys, inspection time typically accounts for 25% of the total assembly time, which in this case is calculated to be 80.7 seconds per assembly.

Labor charges for manual assembly are assumed to be $30 per hour, a standard rate in the industry. Given the total assembly and inspection time of 11.47 minutes (322.82 seconds + 80.7 seconds), approximately 11 scooters can be assembled and inspected within one hour. The assembly cost per scooter is calculated to be $2.72, while the inspection cost is $0.673 per assembly. These costs are derived from the labor charges and the time required for each task.

When considering the total cost of the electric scooter, it is important to account for the part cost, assembly cost, and inspection cost. In this case, the total cost amounts to $186.51 per scooter. However, the scooter's list price on the official website is $440, which is significantly higher than the total cost of production. This difference can be attributed to various factors within the supply chain and the need for the company to generate a profit.

The electric scooter's journey from the manufacturer to the end consumer involves multiple entities in the supply chain, each contributing to the final retail price. After the scooters are manufactured, they are transported to warehouses and distribution centres, incurring logistics costs such as freight charges, warehousing fees, and inventory management expenses. These costs are passed down the supply chain and incorporated into the retail price.

Distributors play a vital role by purchasing the scooters from the manufacturer in bulk, allowing them to negotiate better prices. However, they also need to factor in their operational costs, such as storage, handling, and transportation, as well as their desired profit margin, which leads to an increase in the price as the product moves through the distribution network.

Retailers, as the final point of contact with the customers, also contribute to higher retail prices. They must cover operational expenses like rent, utilities, salaries, and marketing costs while ensuring a profit margin. Additionally, retailers may offer after-sales services, warranties, or return policies, which are factored into the pricing.

Furthermore, the company needs to generate a profit to sustain its operations, invest in research and development, and grow its business. The profit margin is determined by various factors, such as the company's market position, competition, and overall business strategy.

In conclusion, the significant difference between the total cost of production ($186.51) and the retail price ($440) of an electric scooter can be attributed to the complex supply chain involving manufacturers, distributors, and retailers, each with their own operational costs and profit margins. The company's need to generate a profit further contributes to the higher retail price. Understanding these factors helps to explain the pricing structure and the value added at each stage of the supply chain.

4. Conclusion

Design for Manufacturing and Assembly (DFMA) is an engineering strategy aimed at reducing complexities and costs associated with the manufacturing process, particularly focusing on minimizing assembly time and part count. In this analysis, we evaluate the production of an electric scooter, dissecting its assembly and cost implications to illustrate the impact of efficient DFMA practices.

The total assembly time for an electric scooter, a critical determinant of production efficiency and cost, is quantified at 322.82 seconds, or approximately 5 minutes and 23 seconds. This duration encompasses the manual efforts required to handle and assemble the various scooter components. Human operators perform these tasks, which include joining parts and ensuring they fit correctly, highlighting the labor-intensive nature of the assembly process.

Moreover, inspection time is a vital aspect of quality control, accounting for about 25% of the total assembly time, which in this scenario is 80.7 seconds per scooter. This phase ensures that each unit meets quality standards before it moves to the next distribution stage.

Calculating labor costs, which are assumed at $30 per hour, we find that the assembly and inspection combined take about 11.47 minutes per scooter. Given this timeframe, approximately 11 scooters can be assembled and inspected within an hour. This leads to an assembly cost of $2.72 and an inspection cost of $0.673 per scooter. These costs are foundational in understanding the overall expense of scooter production.

However, the total production cost extends beyond labor. It also includes part costs, which, when added to assembly and inspection expenses, amount to $186.51 per scooter. This figure is critical as it forms the baseline for the retail pricing strategy.

The retail price of the scooter is listed at $440 on the official website, significantly higher than its production cost. This markup is not merely a reflection of corporate greed but a necessary strategy to cover additional expenses incurred throughout the supply chain. These include logistics costs such as freight charges, warehousing fees, and inventory management, all essential for getting the product from factory to consumer.

Distributors and retailers play pivotal roles in this markup. Distributors buy bulk from manufacturers, negotiating prices that allow them to cover operational costs while aiming for a profit. Their costs include storage, handling, and transportation. Retailers, as the final link in this chain, incur expenses related to storefront operations, including rent, utilities, salaries, and marketing efforts. They also factor in services like after-sales support, warranties, or return policies, all of which add to the retail price.

Additionally, the company's need for profitability cannot be understated. Profit margins are not just for shareholder returns but are reinvested into the company to foster innovation, fund research and development, and facilitate overall growth. These investments are crucial for sustaining competitiveness in a fast-evolving market where technological advancements and consumer expectations continuously shift.

This DFMA analysis has unpacked the costs associated with producing an electric scooter and illuminated the various stages at which value is added to the product's journey to the consumer. The significant disparity between the production cost and the retail price is justified by the multiple layers of expenses and the value added through services and guarantees that enhance consumer satisfaction and loyalty.

Understanding these elements is pivotal for any company involved in manufacturing and retail. It helps in strategic decision-making concerning production methods, supply chain management, and pricing strategies. Efficient DFMA practices can lead to significant cost savings and enhanced product competitiveness by streamlining production processes and reducing waste. Therefore, this analysis highlights the importance of cost management in manufacturing and emphasizes the need for a holistic approach to pricing and supply chain management to balance cost efficiency and customer satisfaction.

END of Content

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