Material and Process Selection for Ice Maker blades

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Contents

List of Figures

List of Tables

1.1 Countertop Ice Maker

Figure 1:Countertop Ice Maker[1]

Countertop ice makers are compact, stand-alone appliances designed to produce ice within a home, office, or commercial setting without the need for a permanent water line connection. Unlike traditional ice machines integrated into refrigerators or large commercial units, countertop ice makers are portable and can fit on most kitchen counters or other surfaces with access to a power outlet. These devices work by filling a water reservoir inside the unit, which then pumps water into a refrigerated ice tray where the ice forms. Once the ice is frozen, the machine typically uses a mechanism to release the ice into a storage basket [1].

Countertop ice makers are popular due to their convenience, portability, and ability to produce ice much faster than freezer ice trays. Most models can generate a batch of ice in as little as 6 to 15 minutes, with the ability to produce different sizes and shapes of ice, such as cubes, bullets, and nuggets. This makes them ideal for parties, family gatherings, or any situation where a large amount of ice is needed quickly.

1.2 Countertop Ice Maker Auger Blades

Countertop ice maker auger blades are a crucial component in the functionality of ice-making machines, especially those designed to produce flaked, nugget, or gourmet ice. These blades are part of a helical screw mechanism known as the auger, which rotates within the ice maker. The primary role of auger blades is to facilitate the movement of ice from the production area to the storage or dispensing area, while also ensuring the ice is broken down into the desired size and consistency. Depending on the design, auger blades can also play a significant role in preventing ice clumping by maintaining movement within the storage area, contributing to the cooling process by aiding in the distribution of cold air or refrigerant. Made from durable materials like stainless steel to withstand low temperatures and the physical demands of ice crushing, these blades are designed for efficiency, durability, and safety in food handling. The specific type and design of auger blades vary widely across different models of ice makers, reflecting the machine's intended use, the type of ice it produces, and the manufacturer's approach to durability and maintenance.

Figure 2:Countertop Ice Maker Auger Blade[1]

1.3 Discussion of the Need for a Redesign

The need for a redesign of the countertop nugget ice maker auger blades arises from a significant safety concern: the potential for metal blades to break during operation. This failure can lead to small pieces of metal contaminating the ice basket, posing a laceration hazard [2] to users. The failure mechanism at play involves abrasive wear and fracture of the blades. Over time, the continuous contact between the blades and ice causes wear, reducing the thickness of the blades and compromising their structural integrity. This can lead to cracks and eventual breakage of the blades. The forces exerted on the blades during the ice scrapping process also subject them to bending loads, which they must withstand without fracturing to ensure safe operation. The combination of abrasive wear and susceptibility to fracture under shear, longitudinal & bending loads highlights a critical need for material and process selection that addresses these specific challenges. This condition is modelled using rotating blade from Granta Edu Pack performance indices [3].

1.4 Summary of Design Objectives

To address the failures observed in the existing auger blade design, the redesign aims to select materials and manufacturing processes that enhance the durability and safety of the blades. The primary objectives are:

- **Maximize Resistance to Fast Fracture:** Given the fixed blade length and defect size, the new design must ensure that the blades possess a high resistance to fast fracture. This involves choosing materials that are strong enough to withstand the cutting, radial and bending loads encountered during ice scrapping without breaking.

- **Enhance Abrasion Resistance**: To counteract the abrasive wear from continuous contact with ice, the material for the auger blades must be abrasion resistant. This will prevent the reduction in blade thickness over time, thereby maintaining the structural strength of the blades and preventing the formation of cracks [2].

- **Safety and Compliance with Food Regulations:** Any materials selected for the auger blades must be safe for contact with food and comply with relevant food safety regulations [4].

- **Manufacturability and Cost-Effectiveness:** The selection process must also consider the manufacturability of the blades with the chosen materials and processes, aiming for a design that is both cost-effective and feasible to produce at scale.

Material Selection: The material must possess high toughness to prevent fracture and high hardness to resist abrasion. Metals such as steel or any other alloys are known for their strength, toughness, and corrosion resistance could be considered. Additionally, coatings or treatments to enhance surface hardness and wear resistance may be applied. The process of material selection goes like these in below picture

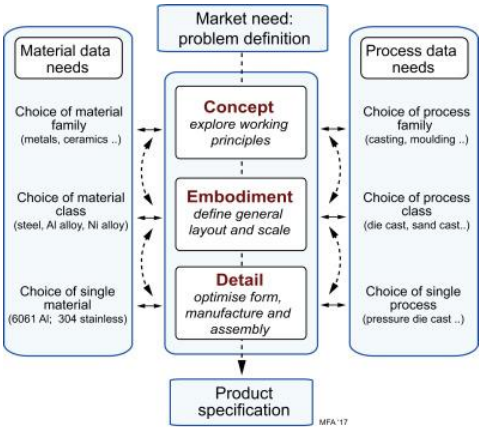

Figure 3:Generalized material and process selection Strategy[5]

Manufacturing Process: Processes that allow for precision in shaping and structuring the blade to minimize stress concentrations, which could lead to cracks and fractures, should be prioritized. Techniques such as forging or powder metallurgy, followed by precise machining and potentially surface treatments for Corrosion, hardness, could be viable options.

2.1 Function:

Ice maker Auger Blades to scrape the ice formed on the inner surface of tube and push it to the top surface for proper shaping (modelled as Rotating blade under abrasion wear and undergoing fast fracture) [3]

2.2 Constraints:

Material and Process Properties	Value
Fracture Toughness – Minimum [6]	45 $\boldsymbol{MPa}.m^{0.5}$
Young's modulus – Minimum [6]	150 GPa
Fatigue Strength at $\mathbf{10^7}$ $\boldsymbol{cycles}$- Minimum	190MPa
Thermal Conductivity - Minimum	15 $\boldsymbol{W}/\boldsymbol{m}$℃
Max Serviceable Temperature -Minimum	$\mathbf{50}$℃
Min Serviceable Temperature - Maximum	-$\mathbf{25}$℃
Durability - Fresh Water	Excellent, Acceptable
Material Price - Maximum	$8/kg
Economic Batch Size - Minimum	8000
Shape	3D Solid

Table 1:Constraint Parameters

2.3 Free Variable:

Choice of material, choice of process, choice of Blade thickness[7]

2.4 Objective Function:

OBJECTIVE FUNCTION	MATERIAL INDEX (Maximize)
Rotating Blade - Resistance to fast fracture; blade length, defect length fixed with minimum cost	$K_{IC}/\rho C_m$
Abrasion resistant design with Sharp contact, static load optimizing resistance to cracking	K_{IC}^4/H^3

Table 2:Objective Function

3.Material Screening and ranking

3.1 Material Screening

The Level 3 database within the GRANTA EduPack software facilitated the identification of suitable materials and process for a selection of material of auger blade of ice maker . This involved selecting from a subset of all bulk materials, excluding fibers, particulates, liquids, and gases due to their unsuitability for the application.

Initially, material constraints listed in Table 1 were applied through a limited stage screening. Additionally, Tree was incorporated into the selection from the process universe to ensure compatibility with 3D solid manufacturing requirements for material selection. Following the application of these limits and the inclusion of Tree, a total of 422 materials out of 3242 were shortlisted, predominantly consisting of steels. This selection was influenced by the necessity for materials with higher fracture toughness, yield strength and fatigue strength. Anyway, surface Treatment for the material for corrosion resistance and food grading were incorporated later.

The process further considered the two material indices mentioned previously. To optimize these indices, the selection lines were iteratively adjusted with a slope of 1, refining the list to 101 materials from the initial 422 that met the criteria outlined in Table 1. The Primary material index, $K_{IC}/\rho C_m$ depicted in Figure 4, where K_{IC} (fracture toughness) is plotted on the Y-axis and on ρC_m (Price × Density) the X-axis [8], was identified as the most critical index to maximize, especially in the context of consumer safety that's Laceration caused by blade. This emphasis is due to the original product recall being attributed to a laceration hazard.

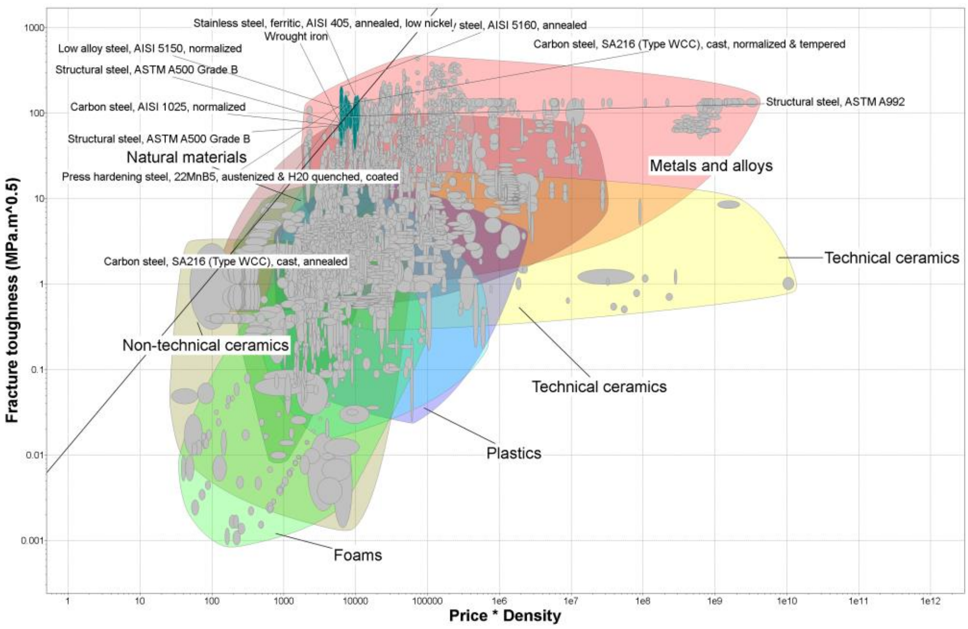

Figure 4:Chart maximizing the material index $K_{IC}/\rho C_m$ for Rotating Blade – Resistance to fast fracture; blade length, defect length fixed with minimum cost. The top materials contenders for this application are labelled, along with their material family.[3]

Additionally, the secondary material index, K_{IC}^4/H^3, aimed at designing for abrasion resistance with sharp contact under a static load to optimize resistance to cracking, is illustrated in Figure 5. This figure plots K_{IC} (fracture toughness) on the Y-axis against H (hardness – Vickers Scale) on the X-axis, with the selection line having a slope of 0.75 [8]. Maximizing this index is also deemed critical for consumer safety, particularly regarding the risk of laceration from the blade. This is because constant abrasion can wear down the blade, reducing its thickness and eventually leading to fracture upon sharp contact. The focus on this index is rooted in the same concern for safety that prompted the original product recall. Through this phase, the list of materials was further narrowed down to 45 from the previously identified 101 candidates.

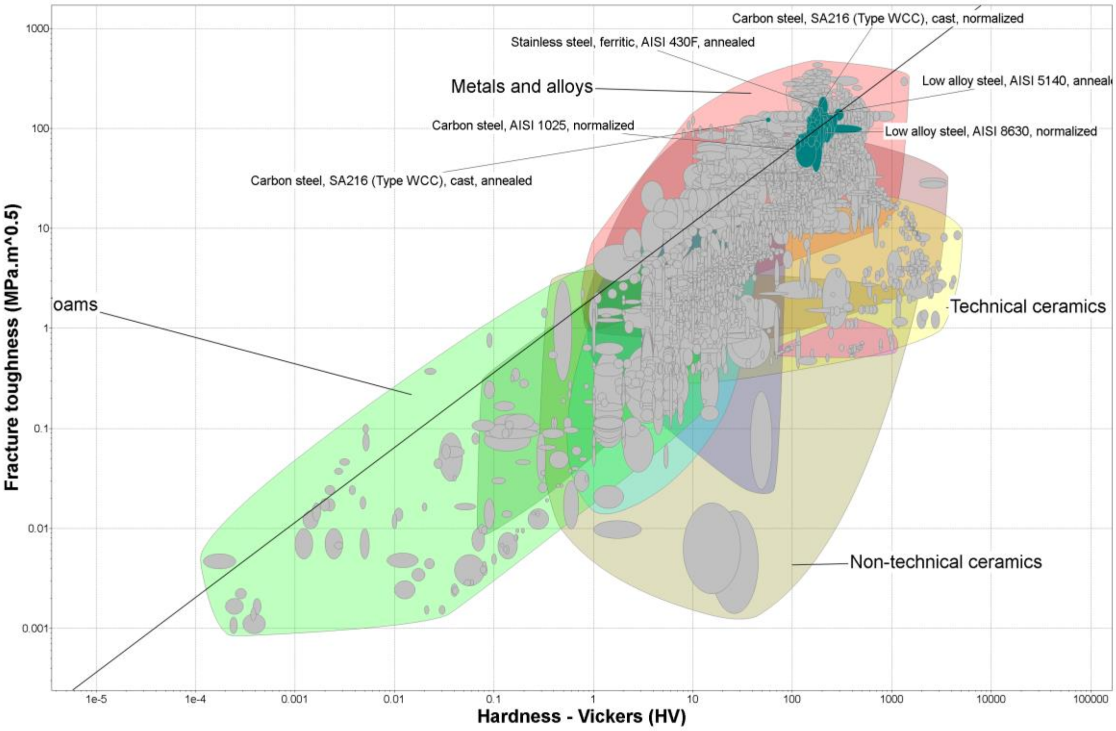

Figure 5:Chart maximizing the material index K_{IC}^{4}/H^{3}, for Abrasion resistant design with Sharp contact, static load optimizing resistance to cracking. The top materials contenders for this application are labelled, along with their material family.[3]

To evaluate the selected materials further, a trade-off curve was constructed, incorporating data from both the Rotating Blade - Resistance to Fast Fracture (with fixed blade length and defect length, aiming for minimal cost, as shown in Figure 4) and the Abrasion Resistant Design with Sharp Contact, Static Load (optimizing resistance to cracking, as illustrated in Figure 5). These indices were prioritized because they align closely with the primary design goals. For the construction of the trade-off plot, each index was reformulated as a variable to be minimized, enhancing the comparative analysis of materials. In the plot, markers for all non-selected materials were hidden to declutter the visual representation, and the plot was zoomed in on the top 6 candidates positioned closest to the trade-off curve. These materials, representing the most efficient solutions (non-dominated solutions), were distinctly marked, and identified in Figure 6.

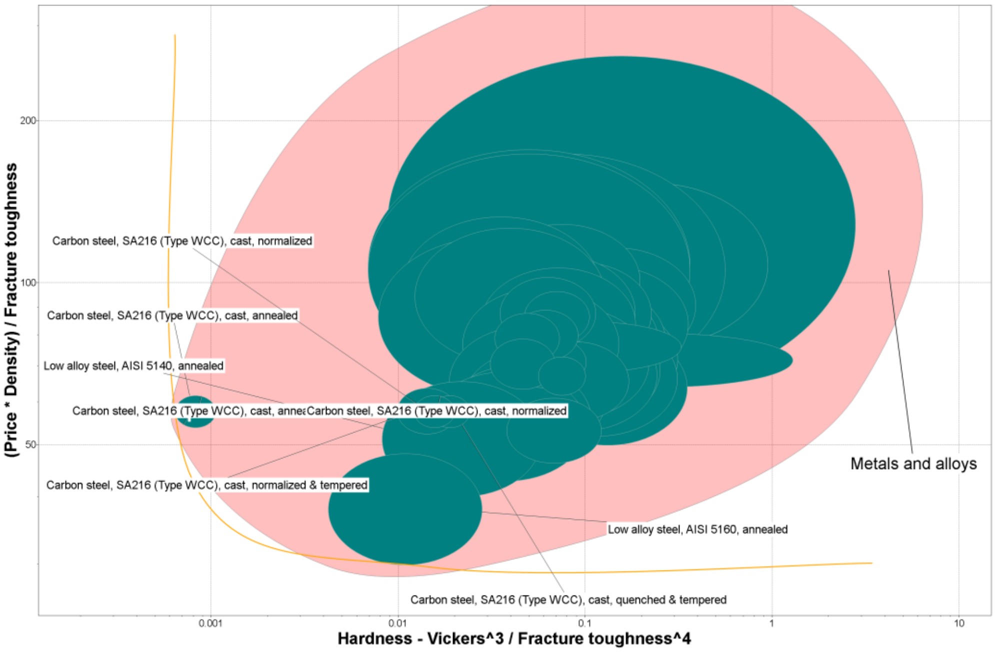

Figure 6:Trade-off plot for Rotating Blade - Resistance to Fast Fracture and Abrasion Resistant Design with Sharp Contact, Static Load . Material bubbles closest to the trade-off curve are identified.

While placement on the trade-off curve suggests that one of these non-dominated solutions will be the top choice for the selection, a more rigorous analysis was performed utilizing weight factors. The shortlisted material along the trade-off curve is listed below, All the options are different type of steel, this is because of high fracture toughness, Abrasion Wear and Hardness Requirements to resist the failure Which couldn't be obtained either through the polymers or ceramics. The Top shortlisted materials are mentioned below.

3.2 Material Ranking

TOP SHORTLISTED MATERIALS
CARBON STEEL , SA216(TYPE WCC), CAST, QUENCHED & TEMPERED
LOW ALLOY STEEL, AISI 5160, ANNEALED
LOW ALLOY STEEL, AISI 5140, ANNEALED
CARBON STEEL , SA216(TYPE WCC), CAST, NORMALIZED & TEMPERED
CARBON STEEL, SA216(TYPE WCC), CAST, ANNEALED
CARBON STEEL , SA216(TYPE WCC), CAST, QUENCHED & TEMPERED

Table 3:Top material contenders

3.3 Weighted Factor

The major reason for prioritizing resistance to fast fracture over abrasion resistance in the material selection for a countertop ice maker's auger blade is the immediate and severe safety risk of laceration to users in the event of a sudden material failure. A fast fracture could result in sharp fragments that pose an immediate hazard, significantly outweighing the slower, more predictable concerns associated with abrasion wear [9]. Ensuring the material's robustness against sudden breakage is essential to prevent potential injuries, making it the foremost consideration in material selection for such applications. Therefore, the Weighted factor for fast fracture have been assigned 0.6 and weighted factor for abrasion wear is assigned 0.4. Weighted value

Weighted Value : 0.6×M1 + 0.4× M2

Normalized Material Index M_a : $M_a/\max\ (M_a)$

M = Material Index

Materials	Resistance for Fast Fracture (M1)	Resistance for abrasion wear(M2)	Normalized (M1)	Normalized (M2)	Weighted Value
1.CARBON STEEL, SA216(TYPE WCC), CAST, NORMALIZED	0.0177	1215	0.66	1	0.796
2.LOW ALLOY STEEL, AISI 5160, ANNEALED	0.0268	100.71	1	0.082	0.633
3.LOW ALLOY STEEL, AISI 5140, ANNEALED	0.0199	50.68	0.742	0.041	0.461
4.CARBON STEEL , SA216(TYPE WCC), CAST, NORMALIZED & TEMPERED	0.0174	81.89	0.649	0.067	0.416
5.CARBON STEEL, SA216(TYPE WCC), CAST, ANNEALED	0.0175	64.12	0.652	0.052	0.412
6.CARBON STEEL , SA216(TYPE WCC), CAST, QUENCHED & TEMPERED	0.0174	52.96	0.649	0.043	0.406

Table 4:Top 3 material Contenders for ice maker blade using weight factor Principle[10]

4.1 Pros & Cons of Top 3 materials

1. Carbon Steel, SA216 (Type WCC), Cast, Normalized

Advantages of Carbon Steel, SA216 (Type WCC), Cast, Normalized

- **Microstructure and Grain Size:** The normalizing process refines the microstructure of SA216, leading to a uniform distribution of fine grains. This not only enhances toughness but also improves homogeneity, which is crucial for consistent performance under varied loading conditions [11].
- **Thermal Stability:** Carbon steel of this grade exhibits good thermal stability. In applications like auger blades, where the temperature can fluctuate, this stability ensures that the steel maintains its structural integrity and mechanical properties over time.
- **Cost and Availability Factors:** Its relative abundance and lower material cost make it a sustainable option for large-scale or continuous production needs. The ease of sourcing also reduces potential delays in manufacturing or maintenance.

Disadvantages of Carbon Steel, SA216 (Type WCC), Cast, Normalized

- **Corrosion Resistance:** Despite its many benefits, SA216 lacks inherent corrosion resistance, making it vulnerable to environmental conditions that can lead to rust and degradation over time. This requires additional maintenance or protective coatings to ensure longevity, especially in moist or corrosive environments [12].
- **Wear Resistance:** While it boasts good toughness, its resistance to wear and abrasion is lower compared to alloy steels like AISI 5160 and AISI 5140. In applications where abrasive wear is a significant factor, this could lead to quicker degradation and the need for more frequent replacement or maintenance.

2. Low Alloy Steel, AISI 5160, Annealed

Advantages of Low Alloy Steel, AISI 5160, Annealed

- **Alloying Elements:** AISI 5160 is a chromium alloy steel, with chromium contributing to its high fatigue strength and excellent wear resistance. The presence of chromium also enhances the steel's ability to resist oxidation and corrosion to a certain extent, though not as effectively as stainless steels.
- **Heat Treatment Sensitivity:** While annealing provides a balanced microstructure, AISI 5160's performance heavily depends on the precise control of heat treatment processes. The steel can achieve various property ranges, making it adaptable but requiring stringent manufacturing controls [13].
- **Application-Specific Advantages**: Its blend of durability and resistance to wear makes it ideal for components like auger blades, which face both high stress and wear conditions. However, the increased cost can be a factor in its selection.

Disadvantages of Low Alloy Steel, AISI 5160, Annealed

- **Cost:** The addition of alloying elements such as chromium increases the material cost of AISI 5160 compared to basic carbon steels. This can impact the overall cost-efficiency of the manufacturing process, especially for bulk or large-scale production.
- **Complex Heat Treatment:** To achieve the desired balance of toughness, strength, and

wear resistance, AISI 5160 requires precise heat treatment processes. This complexity can increase manufacturing time and costs, and requires specialized knowledge to ensure consistency.

- **Corrosion Vulnerability**: Although better than plain carbon steels, AISI 5160's corrosion resistance is not as high as stainless steels or more highly alloyed materials. Protective measures may still be necessary, especially in environments prone to corrosion.

3. Low Alloy Steel, AISI 5140, Annealed

Advantages of Low Alloy Steel, AISI 5140, Annealed

- **Balance of Properties:** AISI 5140 is often chosen for its excellent balance between strength, toughness, and wear resistance. This balance makes it suitable for parts that require significant mechanical performance without the need for the highest levels of wear resistance.
- **Heat Treatability:** Similar to AISI 5160, AISI 5140's properties can be finely tuned through heat treatment. This allows for optimization of the steel's characteristics for specific applications, though it adds complexity to the manufacturing process.
- **Corrosion and Wear Management**: While offering moderate resistance to wear and corrosion, AISI 5140 may require surface treatments or coatings for applications where these factors are critical. This adds to the overall cost and complexity of using this material in a finished product.

Disadvantages of Low Alloy Steel, AISI 5140, Annealed

- **Toughness Compared to AISI 5160:** While AISI 5140 offers a good balance of properties, its toughness, particularly in terms of resistance to impact and shock, is generally lower than that of AISI 5160. This could be a limitation in applications where these characteristics are critical.
- **Heat Treatment for Optimal Properties:** Achieving the optimal balance of mechanical properties in AISI 5140 depends on careful control of the annealing process. This adds a layer of complexity to the manufacturing process, potentially increasing costs and requiring precise quality control.
- **Corrosion and Wear Protection:** Similar to AISI 5160, AISI 5140 requires additional treatments to improve its corrosion and wear resistance for certain applications. This adds to the material and processing costs, making it more expensive than materials with inherent resistance to these elements.

4.2 Final Chosen Material

Carbon Steel SA216 (Type WCC), cast and normalized, emerges as the preferable material for auger blades where minimizing the risk of fractures leading to lacerations is paramount. Its superior toughness, stemming from the normalizing process, significantly enhances its resistance to sudden fractures under dynamic loads. This inherent toughness provides a crucial safety advantage, making SA216 Type WCC especially suitable for applications where failure could have severe consequences. In contrast, while AISI 5160 and AISI 5140 offer higher wear and fatigue resistance, these attributes can be less critical when the primary concern is preventing catastrophic failure modes like fast fractures.

Moreover, SA216 Type WCC holds an advantage in cost-effectiveness and weldability, crucial for large-scale production and maintenance. Its lower material cost, combined with its mechanical robustness, delivers a balanced proposition of performance and affordability. This cost advantage enhances its attractiveness for applications demanding high material integrity without the premium price of alloy steels.

Addressing SA216 Type WCC's comparative shortfall in abrasion wear and fatigue resistance, these can be substantially mitigated through the application of coatings or surface treatments. Techniques such as carburizing, nitriding, or applying advanced ceramic coatings can elevate its wear and fatigue properties to levels comparable with or even superior to those of AISI 5160 and AISI 5140, without compromising its fundamental advantages in toughness and cost.

Considering these factors, the weighted value of SA216 Type WCC's properties for applications at risk of fracture-induced lacerations is notably higher. The possibility of enhancing its wear and fatigue resistance post-production further solidifies its status as the optimal material choice. Through strategic enhancements, SA216 Type WCC not only meets the critical safety requirements but also offers a versatile, economically viable solution for preventing the fast fractures that could lead to serious lacerations.

Figure 7:Carbon Steel SA216 (Type WCC), cast and normalized Plates[14]

4.3 Surface treatment

Within the Process Universe framework, Carbon Steel SA216 (Type WCC), cast and normalized, was categorized using the Tree structure under the Material Universe. Subsequent application of specific constraints—namely, Corrosion Resistance (Aqueous), Fatigue Resistance, a B grade of surface smoothness, and Wear Resistance—resulted in a narrowed selection. Out of 46 potential processes, only one met all the stipulated criteria: Chromizing & Plasma Chromizing which was also very cost effective when chart was plotted with Corrosion resistance on Y- Axis and relative tooling cost on X-axis.

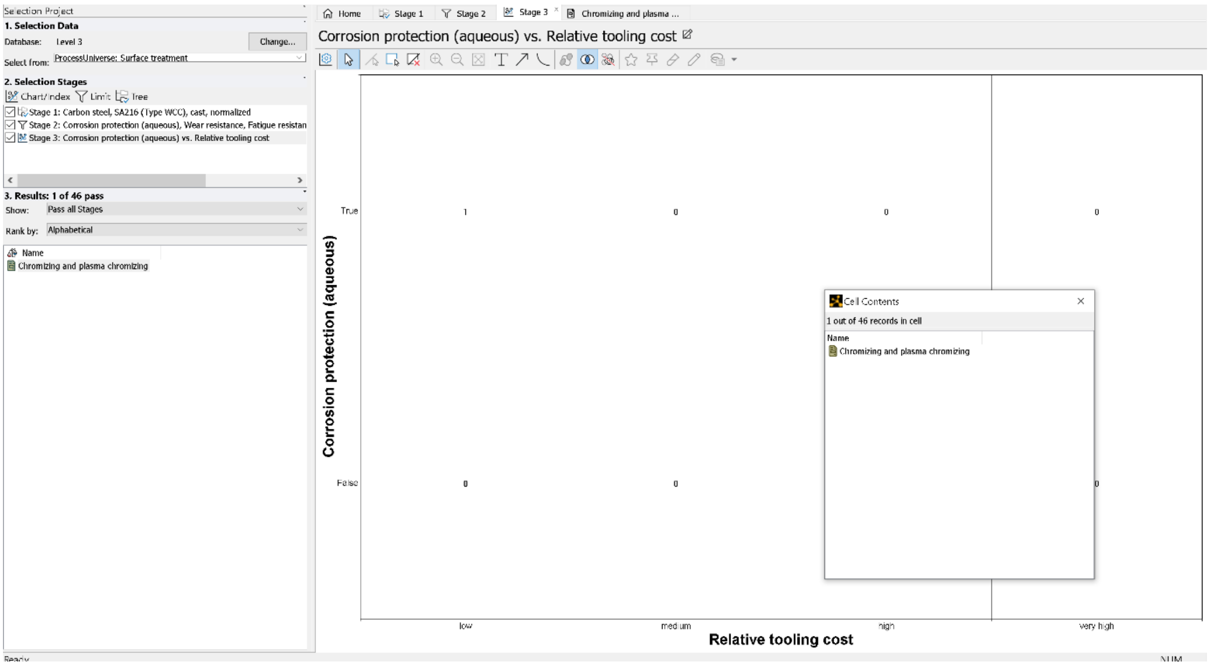

Figure 8:Surface treatment chart under process Universe with shortlisted surface treatment as chromizing and plasma chromizing which is cost effective for given Constraints.

4.4 Chromizing and Plasma Chromizing

Figure 9:Chromising and Plasma Chromising[15]

Chromizing and plasma chromizing are specialized surface treatment processes designed to augment the surface characteristics of metals, notably improving their corrosion resistance, fatigue resistance, surface smoothness, and wear resistance [16]. Chromizing involves the diffusion of chromium into the surface of a metal, such as Carbon Steel SA216 (Type WCC), through a chemical vapor deposition process. This is achieved by exposing the steel to a chromium-containing medium, either in powder form or as a gas, at high temperatures ranging from 900°C to 1100°C. The process allows chromium atoms to penetrate the metal's surface, creating a robust, chromium-enriched layer. Plasma chromizing, a more advanced variant, utilizes a plasma field to enhance the diffusion of chromium, making the process more efficient and effective at lower temperatures and shorter treatment times. Both methods lead to the formation of a protective layer on the steel, significantly enhancing its surface properties.

Applying these surface treatments to Carbon Steel SA216 (Type WCC) transforms its surface, tailoring it for enhanced performance in challenging conditions. The chromium-rich layer significantly bolsters the steel's resistance to corrosion, particularly in aqueous environments, by forming a durable chromium oxide barrier that shields the underlying metal from oxidizing agents [17]. Furthermore, this surface modification substantially increases the material's wear resistance, thanks to the heightened hardness and reduced friction coefficient imparted by the chromium layer. Fatigue resistance sees notable improvement as well, as the treated surface better withstands the stresses and strains from cyclic loading, minimizing the risk of crack initiation and propagation. To achieve a B grade of surface smoothness, the process parameters can be finely tuned, and additional mechanical finishing techniques may be employed post-treatment. This ensures a finely polished surface that not only meets aesthetic and tactile requirements but also reduces the likelihood of material degradation over time. Through these processes, Carbon Steel SA216 (Type WCC) is endowed with a formidable surface that excels in operational longevity and reliability, making it ideal for applications where superior surface qualities are paramount.

5.1 Process Screening

In the Ansys Granta Edu Pack, within the Process Universe tree, a connection was made to the final chosen material, Carbon Steel SA216 (Type WCC), which is cast and normalized. This step is critical because the manufacturing process must be compatible with the material. Not every process is suitable for a given material, so it's essential to select a manufacturing process that can effectively produce the desired material [3].

5.2 Process Constraints

Process Properties	Values
Shape	3D – Solid
Mass range	0.2-1 kg
Range of Section Thickness	0.5 -3 mm
Primary shaping process	Yes
Batch Size (Minimum)	8000

Table 5:Process Constraints

In the case presented in Table 4, specific constraints were applied within the Process Universe tool to identify suitable manufacturing processes for the production of an ice maker auger blade. By setting these constraints, the selection was narrowed down significantly from a total of 146 possible processes to just three viable options: shell casting, Replicast casting, and Centrifugally Aided Casting. Following this filtration based on the set criteria, a comparison chart was created. This chart (figure 10) plotted the primary manufacturing processes on the Y-axis against the Economic Batch size on the X-axis. This visualization was used to assess the relationship between the chosen manufacturing processes and the cost-effectiveness of production at different scales.

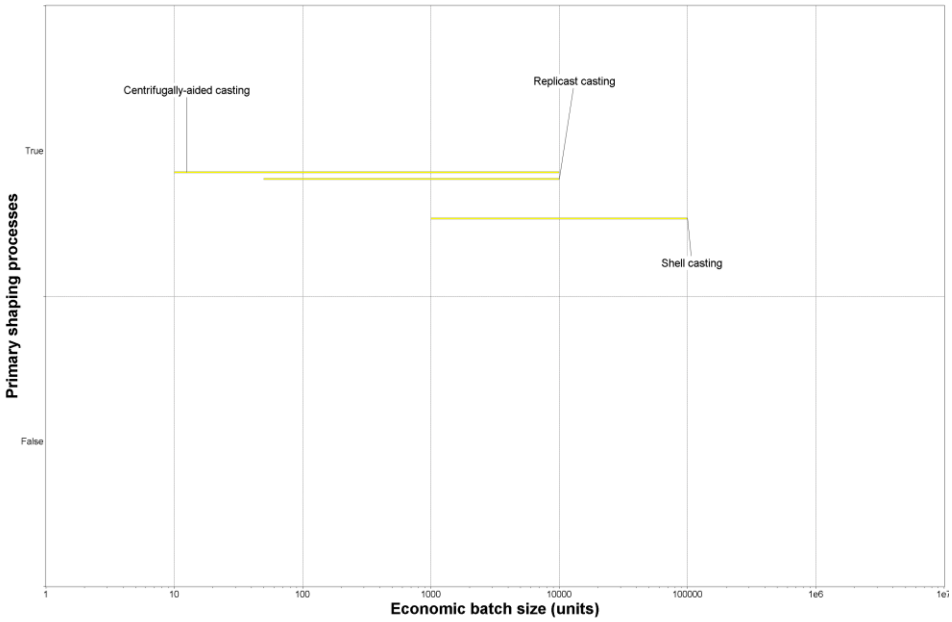

Figure 10: Primary Shaping process Vs Economic Batch Size

At the subsequent stage, the three shortlisted manufacturing processes were further analyzed through bar charts, with the Y-axis representing the relative cost index (figure 11). This analysis aimed to understand how the pricing of the part would fluctuate based on factors such as part complexity and the geographical location of production. The initial observation from the charts indicated that all three processes have similar costs at the lower end of the complexity spectrum. However, as complexity increases, Centrifugally Aided Casting becomes more expensive, marking it as a less cost-effective option compared to the other two processes at higher levels of complexity and production demands.

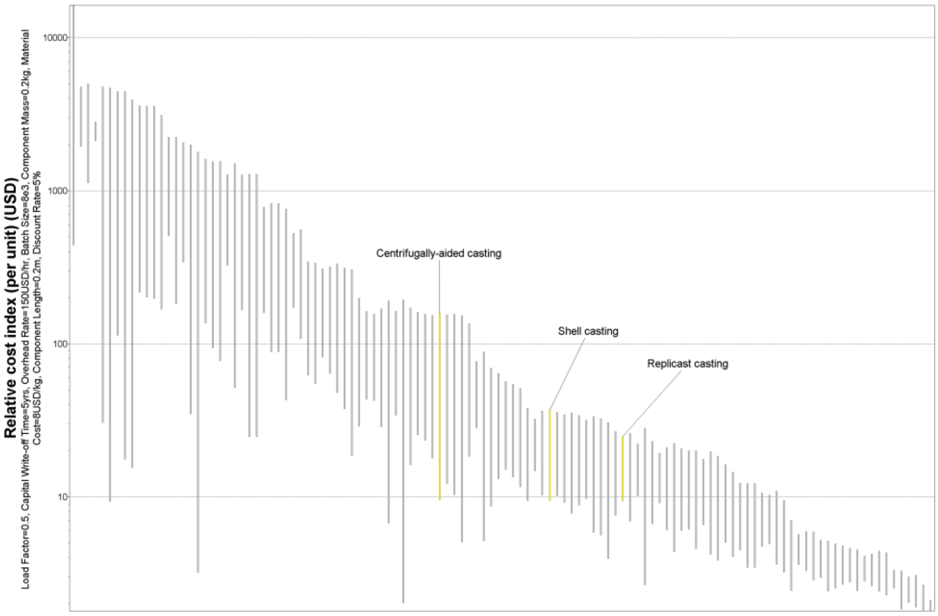

Figure 11:Relative Cost Index Bar Chart

In the later analysis stages, the cost variation for manufacturing batches ranging from 0 to 8,000 (figure 13) units was examined, taking into account selected parameters. Given that the part complexity was deemed easy in this scenario, Centrifugally Aided Casting emerged as the most cost-effective method, even though the cost of using Replicast casting might be slightly higher, only by a few cents. However, should there be a design modification that adds complexity to the part, Centrifugally Aided Casting would then become more expensive. Therefore, in situations where there's potential for increased complexity, Replicast casting is considered a more prudent choice. This is because its cost variability is less sensitive to changes in part complexity, making it a more stable option in terms of pricing over a range of complexities.

Figure 12:Replicast Casting Process[18]

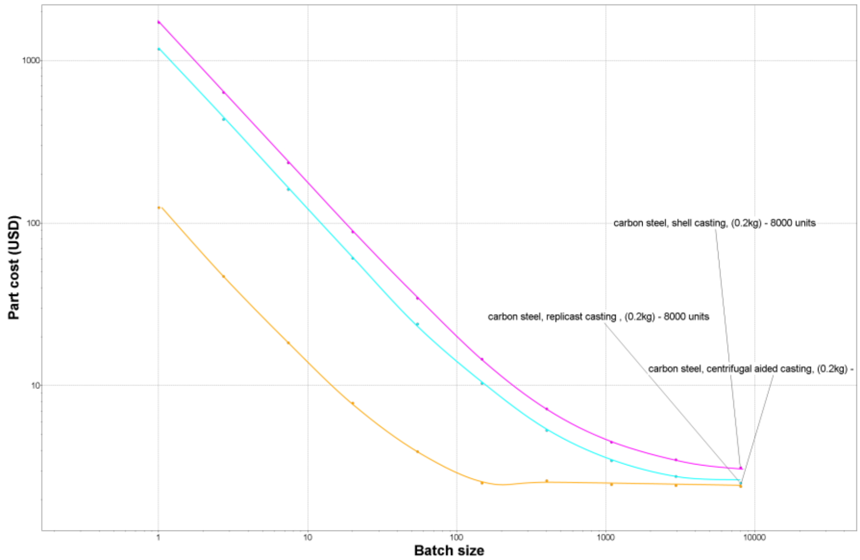

Figure 13:Part Cost vary with Batch Size (1-8000)

5.3 Process Documentation

Replicast casting process

The Replicast casting process is an innovative manufacturing technique that produces metal parts with high precision and excellent surface finish. The process begins with the creation of a detailed foam model of the desired part, which serves as a one-time-use pattern. This foam model is then encased in a ceramic slurry, forming a mold once the slurry solidifies [18]. The key advantage of using foam is that it vaporizes when subjected to the high temperatures during the subsequent step, where the mold is heated. This heating process not only removes the foam but also enhances the strength of the ceramic mold.

Once preheated, the cavity left by the vaporized foam is filled with molten metal, typically through gravity pouring. The precision of the foam model allows for the casting of complex shapes and intricate details without the need for cores or traditional parting lines. After the metal solidifies, the ceramic shell is broken away, revealing the cast metal part. This method is highly valued for its ability to minimize waste and reduce the need for post-casting machining due to the accuracy of the castings it produces. Replicast casting is particularly useful for medium batch sizes where the benefits of reduced material waste and high dimensional accuracy are most pronounced.

Advantages of Replicast Casting:

- **High Precision and Detail**: The use of foam patterns allows for the creation of parts with complex geometries and intricate details, closely mirroring the original design specifications[19].
- **Excellent Surface Finish**: The smooth surface of the foam pattern translates into a superior surface finish of the final cast part, reducing the need for extensive finishing processes.
- **Reduced Material Waste**: Since the process involves the direct transformation of the foam pattern into the cavity for the molten metal, there is minimal material waste compared to traditional casting methods.
- **Cost-Effective for Medium Batches**: The process is particularly cost-efficient for

medium production runs, where the precision and reduced waste offer significant cost savings.
- **No Need for Cores or Parting Lines:** The single-piece foam pattern eliminates the need for cores and parting lines, simplifying the mold design and the casting process.
- **Versatility in Materials:** Replicast casting can be used with a wide range of metals, providing flexibility across different applications and industries.

Disadvantages of Replicast Casting:
- **Initial Costs:** The initial setup costs, including the production of foam patterns and the investment in specialized equipment, can be higher than for some traditional casting methods.
- **Longer Lead Times for Large Volumes:** While effective for small to medium batches, the process may not be as time-efficient for very large production volumes due to the individual preparation of foam patterns.
- Environmental Concerns: The vaporization of the foam pattern releases gases that need to be managed properly to minimize environmental impact.
- **Ceramic Mold Breakage Risk:** The ceramic molds are brittle and can be prone to damage if not handled carefully, potentially leading to production delays or loss of materials.
- **Limited Reparability:** Due to the nature of the process, defects or inaccuracies in the final product are less easily corrected than in some traditional casting processes, potentially leading to increased waste.

6. Conclusion

The meticulous process of selecting the most suitable material and manufacturing technique for a given application encompasses a multidimensional analysis, where variables such as material properties, cost efficiency, and process compatibility are evaluated in depth. This document outlines the rigorous approach undertaken to arrive at the optimal selection of Carbon Steel SA216 (Type WCC), further enhanced by chromizing plating, and the replicast casting process as the most cost-effective manufacturing technique.

Stage 1: Initial Screening and Material Selection

The journey begins with a comprehensive screening process, employing a framework that integrates limits and trees under a 'process universe' model. This initial stage involves evaluating materials based on their mechanical properties, specifically focusing on resistance to fast fracture and abrasion wear. Such criteria are paramount for applications demanding high durability and reliability under stress and wear conditions. Carbon Steel SA216 (Type WCC) emerges as the standout choice due to its inherent grain structure, which significantly contributes to its strength and resilience against fractures and wear.

Stage 2: Surface Treatment for Enhanced Properties

To further augment the selected material's capabilities, a surface treatment method is explored. Chromizing plating is identified as the optimal treatment, enhancing the material's surface hardness and resistance to wear, while also improving its fatigue strength. This decision is arrived at through a systematic evaluation within the 'process universe', ensuring the treatment aligns with the material’s characteristics and the application's demands.

Stage 3: Process Selection and Tree Analysis

Given the varied nature of manufacturing processes, not all are compatible with the chosen material. Therefore, a decision tree specific to Carbon Steel SA216 is developed, incorporating constraints such as the necessity for a 3D-solid form and a primary shaping process. This analytical framework ensures that the process selected not only aligns with the material’s properties but also meets the geometric and structural requirements of the final product.

Stage 4: Cost Analysis and Final Process Determination

The concluding stage involves a detailed cost comparison among the shortlisted manufacturing processes. Through a thorough financial analysis, replicast casting is determined to be the most economical option. This process is compared against alternatives such as shell casting and centrifugal casting, with the analysis covering factors such as production scale, material waste, part complexity and energy consumption.

7.References

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8. Appendix

8.1 Determination of Constraints:

Fracture Toughness: The previous material used for the auger blade in the countertop nugget ice maker was Stainless AISI 316, Annealed. It failed because the blade fractured. To prevent this issue from reoccurring, it's crucial to select a material with higher fracture toughness [20]. According to data from the Ansys Granta Edu pack, stainless steel typically has a fracture toughness ranging from 45 $\boldsymbol{MPa.m1/2}$ .. Any material with a fracture toughness greater than this value would effectively address the problem of fracture formation and propagation in the auger blade, enhancing its durability and performance.

Young's Modulus: The previous material used for the auger in the nugget ice maker was stainless steel, which had a Young's modulus of approximately 150 GPa [21] using Granta Edu pack. Bar chart. A higher Young's modulus indicates greater stiffness, meaning the material experiences less deflection under various stresses. To minimize the risk of blade breakage, which is a primary cause of laceration, we should select a material for the blades with a Young's modulus exceeding 150 GPa.
This ensures that the blades will maintain their structural integrity and resist deformation when subjected to operational stresses, reducing the likelihood of breakage and potential safety hazards.

Thermal Conductivity: Thermal Conductivity plays major role in faster ice formation and resisting the crack formation and propagation. Thermal conductivity of previously used stainless steel was 15 $\boldsymbol{W/m}$°C using Granta Edu pack Bar chart [3]. Auger blades with higher thermal conductivity can efficiently conduct heat away from the ice-making chamber. This helps to rapidly cool the surrounding water or ice particles, promoting faster freezing and ice formation. Variations in thermal conductivity can result in temperature gradients within the auger blades during operation. Rapid or uneven heating and cooling can induce internal stresses, which may weaken the material and increase the likelihood of crack formation or blade failure. Efficient heat transfer from the ice to the auger blades is essential for effective ice breaking and removal. Materials with higher thermal conductivity can facilitate better heat transfer, ensuring uniform cooling of the blades during operation. However, if the blade material cannot adequately dissipate the absorbed heat, localized thermal stresses may occur, potentially leading to thermal fatigue or mechanical failure over time. So higher the thermal conductivity of material used than before. Better the ice maker performance and safety related to laceration.

Fatigue Strength: at 10^7 $\boldsymbol{cycles}$: Fatigue strength directly impacts the susceptibility of auger blades in countertop nugget ice makers to crack formation and breakage [22]. previous material used in the blades failed with a fatigue strength of 190 MPa at 10^7 cycles using Granta Edu pack. Bar chart and normalizing it. It's imperative to consider a material with even higher fatigue strength to mitigate the risk of failure. Blades with improved fatigue strength are less likely to develop cracks and break under cyclic loading, reducing the potential for lacerations during ice consumption. Therefore, selecting a material with superior fatigue strength ensures greater blade durability and safety in use.

Service Temperature: The auger in the ice maker operates within a dynamic temperature environment. On one hand, it encounters extremely cold conditions when in contact with ice, potentially reaching as low as -25°C [23], while on the other hand, it also faces warmer temperatures due to the compressor or ambient surroundings, which can reach up to 50°C. Therefore, the material chosen for the auger must be capable of withstanding this wide range of temperatures without compromising its structural integrity or functionality. This requirement necessitates selecting a material with a high working temperature range to ensure optimal performance and durability under varying temperature conditions.

Durability: When evaluating auger blades for ice makers, it's crucial to consider their ability to withstand exposure to fresh water to prevent corrosion [17] and maintain food safety standards[4]. Initially, this requirement may not be imposed at the outset of the screening process to avoid unnecessarily limiting options. However, after ensuring that all other criteria are met, such as functionality and cost-effectiveness, we can address the need for durability against fresh water. This can be achieved through secondary surface treatments, like coatings or finishes, or by selecting materials with inherent resistance to corrosion. By prioritizing durability in this way, we can ensure the long-term performance and safety of the ice maker.

Manufacturing Constraints: Manufacturing processes are chosen based on several key factors: the compatibility of the process with the chosen material, the complexity of the shape being produced, and economic considerations. When examining images of the auger blade used in the Countertop nugget ice maker, it's evident that the blade has a complex three-dimensional shape. Additionally, with a recall of 8,000 sets of these auger blades, it's essential to select a manufacturing process that can efficiently produce this quantity of individual blade sets at a reasonable cost. This means considering processes that can handle the complexity of the blade shape while also being economically viable for more than 8,000 [2] blade sets.

END