Application of TRIZ Methodology to Casting Process: A Case Study

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ABSTRACT

This paper discusses about how to solve problem arising from casting process by using the TRIZ Methodology. For this research, casting process was selected as the case study for applying the TRIZ methodology to solve the defects arise in the process; theory designed aims to solve the problem innovatively. Initial part of the report discussed about casting process and followed by the common type and cause of defects found in casting process. Further on, discussion in the report continue to discuss about the solution towards casting defects, it is done by using TRIZ methodology (Mini-ARIZ and 40 innovative principles). Principles selected will be applied in this report, it tends show how to solve manufacturing problem in casting and come out with an outstanding solution, which is cost effective and efficient from various aspect. As for result and outcome of experiment, TRIZ implementation brings a major impact towards the result of casting. During the case study, TRIZ application has successfully solved 4 main problems identified in the casting experiment; these defects are surface defects (pinholes), flash formation, rough surface and metallic projection by generating useful guidance and provides direction in future steps. The report also includes the result and verification of solution effectiveness, solution generated outcome has been verified and proven to be effective by experiment. In conclusion, TRIZ successfully solve the problem of flash formation, rough surface, metallic projection and reduce the formation of surface cavities.

Keywords— TRIZ Methodology, Mini-ARIZ, Casting, Pinholes, Flash Formation, Metallic Projection

INTRODUCTION

The Theory of Inventive Problem Solving (TRIZ), derived from the Russian acronym Teoriya Resheniya Izobretatelskikh Zadatch, is a systematic methodology designed to generate ideal solutions for complex engineering problems. Unlike approaches based on spontaneous creativity, TRIZ relies on the study of patterns in problems and solutions, offering predictability and reliability in innovation. Its primary objective is to enhance system ideality by resolving contradictions with minimal resource introduction.

In this project, TRIZ is applied to evaluate its compatibility and effectiveness in addressing defects observed in the casting process. The methodology emphasizes achieving ideality through structured tools such as the contradiction matrix, 40 inventive principles, and Mini-ARIZ. By analyzing contradictions within the system, TRIZ guides the development of solutions that improve performance while minimizing negative trade-offs. The implementation aims to investigate existing problems, identify root causes, and propose optimized solutions that reduce defects and improve process efficiency. Ultimately, TRIZ serves as a strategic framework for overcoming technical challenges in casting, ensuring solutions are both innovative and practically feasible.

LITERATURE REVIEW

Casting is a traditional yet highly versatile manufacturing method wherein a liquid material—often molten metal—is poured into a precisely prepared mold cavity and allowed to solidify into the desired shape. After solidification, the mold is either broken away (in expendable-mold casting) or opened (in permanent-mold casting) to extract the casting ([1], [2]). This process enables the production of complex geometries that would be difficult or uneconomical to manufacture with other techniques ([2], [3]).

A. Casting Methods

Casting methods fall into two main categories: expendable-mold casting, where molds are used once and then destroyed (e.g., sand, investment, lost-foam casting), and permanent-mold casting, which employs reusable molds made of metal such as steel or graphite ([4] - [6]). During pattern and mold design, it is essential that the pattern be removable without damage and that the finalized casting be extracted without harming the mold—a consideration critical in both expendable and permanent mold processes ([7], [6]).

Expendable mold casting refers to a broad category of processes that utilize temporary, non-reusable molds, including sand casting, plaster casting, shell molding, and investment casting (lost-wax technique). These methods typically rely on gravity or simple pressure to direct molten metal into the mold cavity, making them suitable for producing complex shapes at relatively low cost ([1], [2]).

Sand casting is one of the oldest and most widely used metal-forming processes due to its simplicity, cost-effectiveness, and versatility. It is suitable for small to medium production runs and can accommodate a wide range of component sizes—from small precision parts to large structures such as railcar beds. The process involves compacting sand mixed with binders around a pattern to form a mold, which is then assembled with cores if needed. Molten metal is poured into the cavity, allowed to solidify, and the mold is broken to retrieve the casting. Sand casting supports both ferrous and non-ferrous alloys and offers design flexibility with minimal weight limitations ([1], [2]).

B. Casting Defects

Casting defects have long been a critical concern in foundry operations, influencing product quality, mechanical performance, and overall manufacturing efficiency. The foundational classification proposed by [8] organizes defects into seven categories: metallic projections, cavities, discontinuities, defective surfaces, incomplete castings, dimensional inaccuracies, and inclusions or structural anomalies. This taxonomy provided a systematic approach for defect identification and remains widely referenced in academic and industrial contexts.

However, advancements in materials science and process control have prompted refinements to this framework. Recent studies emphasize the need for more granular classifications, particularly within cavity-related defects. For instance, gas porosity and shrinkage porosity are now treated as distinct phenomena due to their differing origins and mitigation strategies [9]. Similarly, microstructural anomalies such as bifilms and lustrous carbon have gained attention for their detrimental impact on fatigue resistance and fracture behavior, necessitating advanced detection techniques like scanning electron microscopy (SEM) and computed tomography (CT) [9].

Surface defects, traditionally grouped under "defective surfaces," are increasingly analyzed in conjunction with metallurgical and thermal factors. Pinholes, blowholes, and hot tears are now considered indicators of complex interactions between mold design, alloy composition, and solidification dynamics ([10], [11]). This shift reflects a broader trend toward integrated classification systems that account for both physical and chemical mechanisms of defect formation.

METHODOLOGY

The implementation of this project relies on systematic innovation methodologies derived from the Theory of Inventive Problem Solving (TRIZ). Two primary tools have been employed:

- Mini-Algorithm of Inventing (Mini-ARIZ)
- Forty (40) Innovative Principles of TRIZ

By integrating Mini-ARIZ with the 40 TRIZ principles, this project adopts a systematic approach to innovation, ensuring that problem-solving is both creative and methodologically sound. This combination enhances the ability to generate breakthrough solutions while maintaining technical feasibility and efficiency.

A. Mini-ARIZ

Mini-ARIZ consists of a program (sequence of actions) for the exposure and solution of contradictions, within Mini-ARIZ there are few important components; they will be used in guiding the process towards seeking the ideal solution.

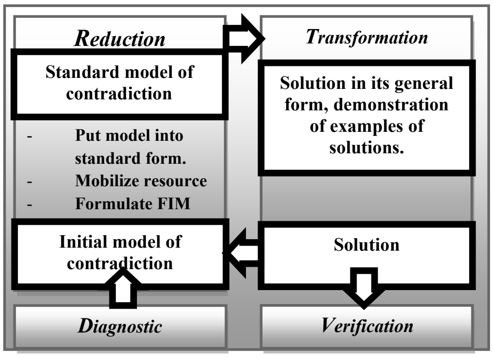

Fig. 1 Mini-ARIZ [12]

B. 40 innovative principles

Engineering parameters represent the characteristics of a system that either improve or deteriorate during problem-solving analysis. In practical applications, these parameters are not restricted to a single positive and negative factor; multiple parameters can coexist when conducting a functional model study. This complexity reflects the real-world nature of engineering systems, where improvements in one aspect may lead to unintended deterioration in another.

To address these contradictions systematically, TRIZ introduces the 40 inventive principles, developed by Genrikh Altshuller based on extensive analysis of innovative solutions across industries. These principles serve as heuristic guidelines for resolving technical contradictions without compromising system integrity. The selection of appropriate principles is facilitated through the contradiction matrix, which maps engineering parameters along its axes and recommends principles based on the interaction between improving and deteriorating features. This structured approach ensures that solutions are both innovative and aligned with the ideality concept central to TRIZ methodology.

C. TRIZ-Based Problem-Solving Phases

The TRIZ methodology, applied through Mini-ARIZ, consists of four key phases: diagnostic, reduction, transformation, and verification.

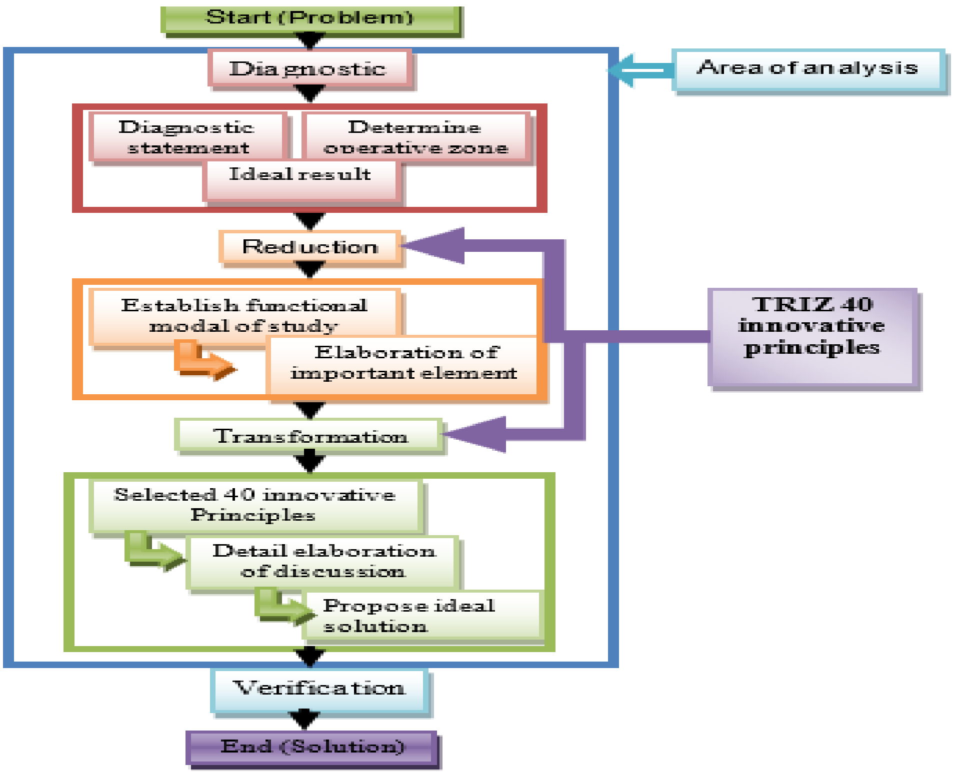

Fig. 2 Flow chart of Mini-ARIZ [12]

RESULTS AND DISCUSSION

Figure 3 show the images obtained from a sand-casting product. There are 3 main types of casting defects found. Description of the defect on the product (image at location 5) is explained by Table 1.

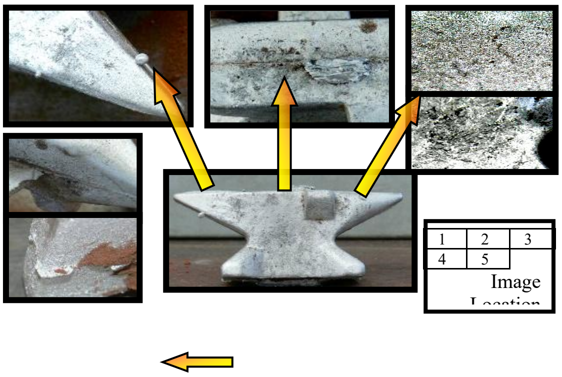

Fig. 3 Casting defects observed from sand-casting product

TABLE I Description of defects shown in Figure 3

Image no	Defects
1	Metallic projection (sweating).
2 & 3	Surface cavity (pin holes) and Rough Surface.
4	Flash formation.

A. Solving Problem of Flash Formation.

Diagnostic: Flash formation is observed as an accumulation of excess material along the parting line of the casting. This defect occurs when molten metal penetrates gaps between the cope and drag boxes, typically due to improper alignment or insufficient compaction of the greensand mold. The resulting flash extends along the edges of the casting, with its length and thickness varying randomly across different sections. Although flash is generally superficial, its presence leads to significant material waste, as the excess metal is classified as scrap. Furthermore, the removal of flash requires additional machining or finishing operations, which increases production costs, prolongs cycle time, and consumes extra resources. Flash formation in sand casting can be affected by the following factors:

TABLE II Operative zones affecting the formation of flash

Operative zone	Explanation
Compression of greensand	Compression of greensand plays an important role in determining the density of the greensand. A loosely compacted sand is prone to form free space between the parting line area, when molten metal is being pour into sand mould, chances of forming flash at the edges of casting is relatively high.
Temperature of the molten metal	Temperature of the molten metal also can contribute to the formation of flash; increase of the temperature in molten metal will decrease the viscosity of molten metal, chances of molten metal flood the space between the parting line will increase as well.
Parting line in sand mould	Parting line in sand mould is the main reason for the formation of flash throughout casting edges. If there is parting line, casting will always form flash on the edges disregarding its size.

Operative zone is the epicenter of the problem; this is where it lays the key towards solution, and TRIZ believes that solution can be found within the system and environment surrounding the process. The final ideal result would be forming a casting which requires no extra process to remove the flash.

Reduction: Several potential solutions have been identified to address flash formation in the casting process from these operative zones, based on the influencing factors observed during practical work:

Increase compression of greensand

Enhancing greensand compaction could reduce gaps at the parting line; however, manual compression has limitations. Transitioning to mechanical ramming (approximately 100 psi) would significantly increase production costs. Moreover, excessive compaction may restrict gas venting, leading to secondary defects such as gas blow pinholes [13]. Therefore, this approach is not recommended as a primary solution, given its cost implications and potential quality trade-offs.

Change type of sand

Altering the sand type may improve mold integrity, but this option also incurs higher material and process costs. Consequently, it is considered less favorable compared to other alternatives.

Control temperature of molten metal

Regulating molten metal temperature is a practical and cost-effective measure. While this adjustment may reduce flash formation, its effectiveness depends on whether the root cause lies in the mold rather than the metal. Thus, temperature control should remain a secondary consideration for future process optimization.

Remove the parting line in sand mould

Eliminating the parting line appears impractical, as sand molds require separation for pattern removal. Although this idea seems unconventional, it introduces a clear technical contradiction—removing the parting line while maintaining mold functionality. This contradiction provides an opportunity to apply TRIZ methodology, specifically Mini-ARIZ, to explore inventive solutions that could reconcile these conflicting requirements.

TABLE III Functional model of study for flash reduction

Objectives	**Positive factors**	**Improved 39 features.**
Remove the parting line in the sand mould.	Remove the flash formation.	• 05 precision of manufacturing.
	Negative factors	**Deteriorate 39 features.**
	Increase complexity of making the mould.	• 07 complexity of construction.

The functional model analysis identified two key factors: a positive factor, representing the benefit of eliminating flash, and a negative factor, indicating increased complexity in mold construction. Logically, the removal of the parting line would result in a flash-free casting, highlighting the trade-off between improved product quality and the deterioration of manufacturing simplicity.

When utilizing TRIZ's 40 inventive principles, it is essential to evaluate the significance of the problem before proceeding with solution generation. In this case, the improved and deteriorated factors were deliberately switched to prioritize mold construction complexity as the dominant concern. This adjustment ensures that the solution aligns with practical manufacturing constraints while still addressing the primary objective of reducing flash formation.

TABLE IV 40 Innovative principles for parting line removal

Deteriorated features / Improve		
Improve	40 innovative	05 Precision of

d	principles	manufacture.
features	07 Complexity of construction.	9,10,18

Transformation: The analysis conducted during the reduction phase identified several guiding principles from the TRIZ contradiction matrix. These principles serve as strategic recommendations for resolving the identified contradictions and are instrumental in generating innovative solutions. The filtering process ensures that only principles relevant to the specific application are considered, thereby improving the efficiency and practicality of subsequent solution development. Before advancing to the transformation phase, the selected principles must be clearly stated and justified based on their applicability to the problem context.

TABLE V Principle to remove parting line

No.	Selected Principles
1	Principle 9, Change in color. (Optical property changes.)
	Change the color of an object or its external environment. Change the transparency of an object or its external environment.
	Not relevant or unusable as guidance.
2	Principle 10, Copying.
	Instead of unavailable, expensive, or fragile objects, use simpler, inexpensive copies.
	Use something inexpensive to cover or replace on the parting line area.
3	Principle 18, Mediator. (Intermediary)
	Use an intermediary carrier article or intermediary process. Merge one object temporarily with another (which can be easily removed).
	Use something to seal or attach the parting line, it can be removed later.

To completely remove the parting line is technically infeasible due to mold separation requirements, the selected principles suggest strategies such as introducing intermediary processes or utilizing less expensive materials to mitigate the issue.

For instance, Principle 18 (Mechanical Vibration/Intermediary) advocates the use of an intermediary mechanism or process to temporarily merge components, thereby reducing the impact of the parting line during casting. Similarly, Principle 10 (Prior Action/Inexpensive Material) emphasizes incorporating simpler or cost-effective materials near the parting line area to minimize flash formation without significantly increasing production costs. These principles serve as a foundation for developing inventive solutions that balance technical feasibility, cost efficiency, and process ideality.

B. Solution for Flash Formation.

The main objective in this study is to eliminate or minimize the parting line in the sand mold, which is the root cause of flash formation.

Principle 10 suggests replacing unavailable, expensive, or fragile objects with simpler and inexpensive copies. Applied to this case, the concept involves using a copying material to fill or cover the parting line gap, thereby reducing flash formation. This approach aligns with industrial practices where greensand is often used to adhere to spaced areas along the parting line. However, reliance on manual skill for greensand application introduces variability, making this solution less reliable for large-scale production.

Principle 18 advocates the use of an intermediary carrier or process to temporarily merge two objects. In this context, an intermediary adhesive or mechanical fixture could be employed to join the cope and drag sections of the mold during casting. This temporary merging would eliminate gaps at the parting line, reducing flash formation without permanently altering mold design. The intermediary should be easily removable post-casting and should not contaminate the greensand, ensuring process integrity.

By integrating these principles, the solution evolves from manual greensand application to a more systematic approach involving adhesive mediators or alternative materials. This not only improves consistency but also reduces dependency on operator skill, paving the way for a more controlled and efficient casting process. TABLE VI suggest the most appropriate solution for the problem.

TABLE VI Parting line solution (silicone characteristic)

Solution	Tools	Characteristic
Applies silicon gasket evenly around the parting line to seal it.	Use hi-temperature RTV silicone gasket maker.	• Hi-temperature silicone gasket. • Resist up to 343ºC

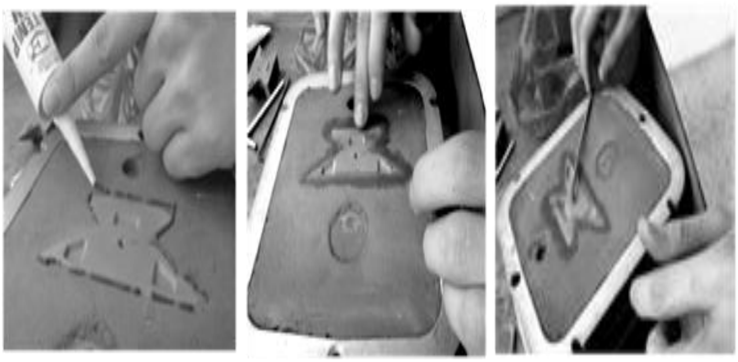

Fig. 4 Sequential steps of preparing silicone solution to apply, distributes and removal of pattern.

C. Problem Solving of Surface Defect

Two primary surface defects were identified during the casting process: metallic projections (commonly referred to as sweating) and surface cavities with rough textures. Both defects share a common characteristic—they occur on the external surface of the casting. For analytical efficiency and comprehensive problem-solving, these defects are categorized together. This approach enables the development of solutions that address both issues simultaneously, ensuring that corrective measures are not only effective but also economically viable. By considering these defects collectively, the proposed solutions aim to optimize surface quality while minimizing additional resource requirements.

The final aim will be to achieve an ideal casting outcome that meets the highest standards of quality and efficiency. Specifically, the final casting should be completely free from metallic projections, exhibit improved surface smoothness, and eliminate the presence of cavities or rough textures. Furthermore, the casting should require no additional finishing operations, thereby reducing production time, minimizing resource consumption, and ensuring cost-effectiveness. It starts with identifying the operative zones presented in TABLE VII along with detailed explanations of their relevance to the casting process and their contribution to the formation of defects.

TABLE VII Operative zones affecting the surface defect

Operative zone	Explanation
Compression of greensand	Compression of greensand plays an important role in determining surface of the casting. Loosely compacted sand will cause the formation of the rough surface, it is cause by molten metal taking the pattern of the mould's surface.

	Worst case, some will cause sand inclusion or air bubbles filling in metal to lodge in the broken area.
Height of the pouring	Height of the pouring process will cause the formation of the air bubble which then contributes to formation of bubbles or micro-cavities near the surface of casting.
Technique of pouring	Technique of poring indicates that pouring passages too long will yield to excessive turbulence and slag formation during pouring.
Composition of greensand	Moisture, nitrogen content, and lustrous carbon content are vital composite that determine the quality of the surface finishing.
Type and grades of greensand	To achieve good surface finishing, it is very important to use fine grade and right type of greensand in order to obtain smooth surface finishing.

These ideas generated are proposed to improve surface finishing and prevent metallic projection:

1. Increase compression of greensand.
2. Control the composition of the greensand and technique of handling process.
3. Make mould surface smoother.
4. Remove the moisture on the mould area.

Generally, all solutions proposed towards the elimination of both problems should be simple and low cost; any solution that yields to high investment will be put out of consideration. From the *Reduction* arguments, only idea (iii) and (iv) will be accepted and proceed. By looking into the 39 features, the functional model highlights key trade-offs in achieving improved surface quality of the cast. The positive factor identified is the enhancement of surface finish, which directly contributes to higher manufacturing precision (no. 5). Conversely, the negative factor involves the increased force required (30) for greensand compaction, leading to greater complexity (7) in mold construction and extended preparation time (25).

Similarly, moisture removal from the mold surface requires better manufacturing precision that presents another contradiction. While reducing moisture can improve surface finish and minimize defects such as pinholes, excessive removal compromises the structural integrity of the greensand mold. Moisture is essential for maintaining mold compact ability; its absence can cause the mold to collapse, whereas its presence may lead to gas-related defects. This scenario illustrates the inherent contradiction—moisture must be retained for mold stability yet minimized to prevent surface imperfections leading to identification of complexity of construction (7), stability of object's composition (29) and quantity of substance/quantity of matter (26) as the deteriorating features. Addressing this contradiction requires inventive strategies that balance these opposing requirements without sacrificing process efficiency or product quality.

TABLE VIII 40 innovative principles for solving casting surface problem

	Improved features	
	40 innovative principles	05 Precision of manufacturing
Deteriorate features	07 Complexity of construction.	5,6,10
	25 Loss of time	4,6,9,10
	26 Quantity of substance/ quantity of matter.	9,25
	29 Stability of object's composition.	6,25
	30 Force	4,8,15,26

Explanation of the 39 features selected in relation to the sand-casting process is describe as followed:

1. Precision of manufacturing, extent to which the actual characteristic of the system or object match the specified or required characteristic. In this case, casting involved in the process will take form from the greensand mould; its entire characteristic will take place from sand mould used in the process.

2. Complexity of construction, number and diversity of elements and element interrelationships within a system. User may be an element of the system that increases the complexity. The difficulty of mastering the system is a measure of its complexity. The complexity of construction of the sand mould requires the presence of moisture to form a firm cavity wall. However, the presence of moisture in the mould will cause the formation of gas blow pin holes. Besides, question also raise when making of mould to be more compact but obstruct the venting of waste gas.
3. Loss of time, time is the duration of the casting process. Time consumed by the process to make the mould will be longer.
4. Quantity of substance/ quantity of matter, the number or amount of a system's material, substance, parts or subsystem that might be changed fully or partially, permanently or temporary. Moisture in the greensand if excessive removal will directly impact the ability of compact of greensand and affect the mould quality.
5. Stability of object's composition, wholeness or integrity of the system relationship of the system's constituent element's, wear, chemical decomposition and disassembly are all decrease in stability. The loss of moisture in sand mould directly affects its ability to form the sand mould properly; mould cavity might fall apart easily when both the cope is being close.
6. Force, force is the interaction of the system, if greensand is to be compacted more densely; more force is required to compress the greensand to achieve more compacted sand density.

Before proceeding with further analysis, the relevant principles will be outlined below, chosen based on their applicability to the situation. In the current attempt to develop solutions, certain modifications have been introduced compared to the previous approach; these changes aim to address both surface defects simultaneously rather than tackling them individually. The acceptance of principles is at the discretion of the user; it is not mandatory to adopt all selected principles as part of the guidance. In most cases, the chosen principles reflect the user's level of understanding. The number of principles applied does not influence the accuracy of the outcome. However, the selection of principles does affect the approach and direction taken toward achieving the solution.

TABLE IX Principles to remove surface defects

No.	Selected Principles
1	Principle 04, Replacement of mechanical matter.
	Use of electrical, magnetic or electromagnetic fields for the interaction of objects.
	Not relevant or unusable as guidance.
2	Principle 05, Separation (remove moisture)
	Separate the incompatible parts/property or separate the necessary parts /properties from the object.
	Moisture is removed from the surface instead of removal of moisture from all the green sand.
3	Principle 06, use of mechanical oscillation.
	Cause the object to vibrate or raises the frequency or application of quartz vibrators.
	Not relevant or unusable as guidance.
4	Principle 08, periodic action (when to apply film or mould reconditioning)
	Transition of continuous function to a periodic one (impulse). Change the periods if the function already runs that way: or use the breaks between impulse for other function.
	Apply periodic action to removal of moisture and all other applicable field.
5	Principle 09, change in color.
	Change the color of an object or its external environment. Change the transparency of an object or its external environment.
	Not relevant or unusable as guidance.
6	Principle 10, copying (use inexpensive material to make film)
	Instead of unavailable, expensive, or fragile objects, use simpler, inexpensive copies.
	Use inexpensive/simpler copies material to smoothen the mould surface.
7	Principle 15, discard and renewal of parts.
	Parts that have fulfilled their task and no longer part of an object should be disposed of (dissolved, evaporate, etc), or use parts of an object should be immediately replace during the work.
	Make the insertion of film requires less steps to remove or easier to discard.

8	Principle 25, Use of flexible covers and thin films.
	Flexible covers and thin layers are used in place of the usual constructions; isolate objects from the external world with flexible covers or thin layers.
	Use thin film to smoothen mould surface
9	Principle 26, phase transition
	Full use of phenomena that occurs during phase transition such as a change in volume, radiation or absorption of warmth, etc.
	Not relevant or unusable as guidance.

D. Solution for Surface Defects.

The primary objective of this study is to address surface defects in castings. The following sections provides a detailed explanation of each TRIZ principles corrective action chosen and implemented for this objective.

Principle 05 focuses on isolating incompatible properties or retaining only essential characteristics. This approach is effective for mitigating surface cavities in green-sand moulds, which partly result from moisture. Moisture reacts with molten metal, forming oxides and atomic hydrogen that diffuse into the melt, creating cavities.

While baking the sand can reduce moisture, excessive drying weakens mould integrity. Moisture and clay form a cohesive film that locks sand grains during ramming [14]. Over-removal of moisture leads to fragile mould and collapse—a clear contradiction.

The moisture removal is achieved by applying Principle 05, which involves localized drying of the molten contact area. The cavity surface is heated to approximately 120 °F using a dryer, effectively reducing surface moisture without exceeding 130 °F—a threshold beyond which clay adhesion deteriorates significantly [15]. Additionally, the bonding strength of the sand–bentonite–water mixture decreases markedly above 50 °C and becomes negligible beyond 70 °C [16].

Fig. 5 Heating process to remove moisture, temperature at 120ºF

During the heating process, both the upper and lower mould cavity has been heated by a dryer before followed by pouring molten the metal into cavity.

Principle 08 is the second principle that involves converting a continuous process into a periodic one or adjusting the intervals of an existing periodic function. It can also utilize breaks between cycles for other operations. In practice, psychological resistance often precedes the adoption of new ideas, as seen in this case study. Traditionally, practitioners attempted to eliminate moisture by drying greensand before casting. However, this approach introduces a contradiction: while drying reduces moisture, it also decreases compactability, causing mould cavities to collapse. Practitioners desire both dryness and the structural integrity provided by moisture. Applying Principle 08 resolves this contradiction by altering the sequence—forming the mould first, then periodically applying heat using a dryer to cure the greensand without compromising its compact ability.

Principle 10 is the third option that advocates using inexpensive or readily available substitutes instead of costly or fragile materials. It is particularly effective for addressing surface roughness and metallic projections in castings. Surface roughness often results from greensand grain size, where finer grains improve contact but reduce permeability [14]. Metallic projections occur when air bubbles near the pattern or thin sand layers break during casting, allowing molten metal to fill voids. To mitigate these issues, introducing fine material to fill cavity irregularities is recommended. A thin film is applied at the cavity–molten interface, as suggested in earlier principles. For this case study, plaster (gypsum) was selected as an economical alternative to carbon powder, which is commonly used in ferrous casting to enhance surface finish [17].

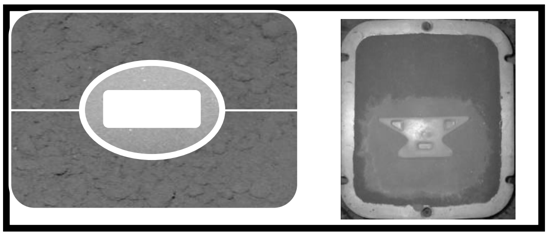

Fig. 6 Discardable film or covers of mixture of greensand and gypsum, picture at left indicates sectioned side view and picture at right indicates the top view

Principle 15 suggests removing components that have completed their function or replacing them during the process, while Principle 25 involves using flexible layers or thin films instead of conventional structures to isolate objects from external influences. Both final principles provide guidance on the characteristics of surface films and were instrumental in developing the concept of applying a mixture of greensand and plaster to the mould cavity surface. These principles target surface-related issues such as roughness, metallic projections, and cavities. Initially, psychological barriers existed, as practitioners assumed that adding additives like gypsum or plaster would require scraping greensand after each use—a valid concern when the sand composition changes. However, this challenge can be addressed by introducing additives only on the surface layer of the mould cavity. This approach minimizes material removal, and if the film becomes unsuitable or unnecessary, the plaster–greensand mixture can be easily removed by digging off the surface layer.

Experimental results confirmed that adding gypsum or plaster improves mould hardness and facilitates casting extraction without disturbing cavity dimensions—an additional benefit of using additives. Furthermore, a new idea emerged whereby scraped greensand can be reused as filler around the mould cavity, while freshly prepared greensand mixed with the desired amount of gypsum or plaster serves as the contact layer for the cavity.

E. Verification of Solutions

The effectiveness of the proposed solutions will be assessed by determining the extent to which the stated objectives have been achieved and whether the desired outcomes were produced. In this study, four major surface defect issues were identified earlier. These defects are categorized below, accompanied by a table summarizing their status after the application of corrective measures.

TABLE X TABLE BEFORE AND AFTER TRIZ IMPLEMENTATION

No	Defects	Before	After	Remark
1	Metallic projection (sweating)	Detected	Removed	No metallic projection has been detected after implementing TRIZ solution.
2 & 3	Surface cavity (pin holes) and rough surface	Detected	Improved	Rough surface has been dramatically improved. Surface cavity of casting surface has also been improved.
4	Flash formation.	Detected	Removed	After solution has been implemented, no flash is detected nor does extra process is required

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Figure 7 indicates the casting surface of before and after TRIZ implementation. The image at the right indicates the presence of metallic projection on casting surface before implementing TRIZ solution; whereas Figure 8 left image indicates casting surface after implementing TRIZ solution that is free from metallic projection. Casting after improvement shows that it is completely free from any metallic projections, verification of metallic projection can be verified via bare eye inspection.

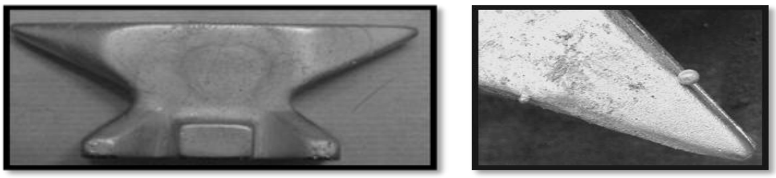

Fig. 7 Casting after TRIZ improvement showing no metallic projection defects (left) as detected from previous casting (right)

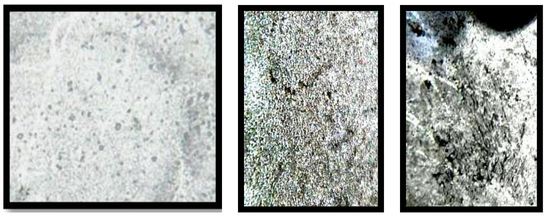

Fig. 8 Images showing surface after TRIZ improvement (left) after TRIZ improvement on rough surface produced earlier (middle and right)

Surface roughness was measured using a profilometer. Two representative areas—the smoothest and the roughest regions of the casting surface—were selected, and their measurements were averaged to determine the overall surface roughness.

TABLE XI Surface roughness result

Surface roughness of casting (R_a)	Smooth		Rough		Average Value
From raw material	6.05 µm	6.16 µm	16.15 µm	11.86 µm	40.22/4=10.055 µm
Conditioned mould cavity without heating (random trial)	5.84 µm	4.38 µm	8.79 µm	7.69 µm	26.7/4=6.675 µm
Conditioned mould cavity with heating (control parameters)	1.64 µm	1.78 µm	2.25 µm	3.53 µm	9.2/4=2.3 µm

Comparison of both surface roughness yields to dramatic improvement of 77.13% that is determined by the following formula:

$$\frac{(Raw - Conditioned\ heating\ cavity)Ra}{Raw\ Ra} \times 100\%$$

Figure 9 compares the parting line area of the casting before and after TRIZ implementation. The image on the left illustrates the improvement achieved, while the image on the right shows flash formation along the parting line. Flash formation typically requires additional removal processes, increasing both time and manufacturing costs. The TRIZ-based solution effectively eliminated flash by removing the parting line in the mould cavity, thereby preventing molten metal from forming excess material. As a result, the casting produced using the

TRIZ-recommended technique is free from secondary finishing operations, and the parting line is smooth and safe to handle without sharp edges.

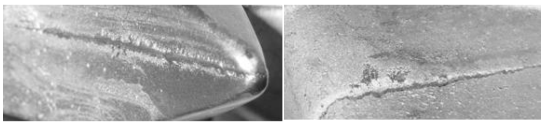

Fig. 9 Comparison at parting line area using bare eye, left is after and right is before TRIZ implementation

CONCLUSIONS

The effectiveness of TRIZ-based solutions in addressing casting defects was validated through experimental implementation. For the primary issue of flash formation, the application of TRIZ principles successfully minimized flash along the parting line. This improvement eliminated the need for additional finishing operations, resulting in significant reductions in manufacturing time and cost.

The second category of defects—comprising metallic projections, surface roughness, and porosity—also demonstrated substantial improvement. Surface roughness was reduced by 77.13%, as confirmed through profilometer measurements, while porosity formation was minimized. Metallic projections were eliminated, with no visible occurrences detected during visual inspection. These outcomes were achieved through TRIZ-guided solutions, including the application of a plaster/gypsum–greensand mixture on cavity surfaces, a technique derived from the 40 inventive principles.

Verification involved multiple testing methods, such as surface profilometry and optical microscopy, to ensure accuracy and reliability of results. Additionally, a controlled experiment was conducted to determine the optimal gypsum proportion in greensand, later cross-referenced with standard literature.

In conclusion, TRIZ methodology proved highly effective in solving the identified casting defects. The approach not only achieved the primary objectives but also demonstrated practicality and adaptability for real-world manufacturing environments. By systematically addressing contradictions and applying inventive principles, TRIZ enabled innovative, cost-efficient, and resource-conscious solutions, reinforcing its value as a robust problem-solving framework in casting processes.

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