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Reverse Engineering of a Submersible Pump Cover Using 3D Scanning and Additive Manufacturing Technology

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ABSTRACT

Submersible pumps are commonly used to handle heterogeneous fluids, including water, mud, gravel, and other sediments, particularly in traditional coal mining operations. A submersible pump used by a conventional coal mining company in Bayah City exhibited severe corrosion after approximately one week of service. Corrosion-induced perforations in the pump cover obstruct suction, thereby reducing mining productivity and necessitating weekly replacement. This reverse engineering (RE) study aims to generate accurate product geometry data for further development and to enhance the corrosion resistance of the pump casing beyond one week of operation, thereby improving mining productivity through reduced maintenance downtime. The RE workflow integrates 3D scanning, CAD remodeling, finite element analysis, additive manufacturing (AM), and field testing. The process successfully produced a high-fidelity 3D geometric model of the pump cover suitable for product development and yielded a redesigned pump cover manufacturable via injection molding with a maximum deformation of 0.75 mm and a maximum von Mises stress of 17.6 MPa. Simulation results indicate an outlet water flow rate of 0.2 m^3/min, while field testing demonstrates that the improved pump cover can operate for more than six months. This study contributes to the advancement of reverse engineering applications in mining equipment by demonstrating an integrated digital engineering framework that combines 3D scanning, computer-aided design, numerical simulation, additive manufacturing, and field validation to accelerate product redesign and significantly improve the service life of corrosion-prone components. Next research recommendations should focus on material optimization and surface treatment to enhance durability. Innovation opportunities lie in advanced casting routes combined with microstructure control and protective surface coatings to improve performance and service life.

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1. Introduction

Reverse engineering (RE) is a systematic process for analyzing a human-made object to understand its internal functions, operating principles, or design intent, to reproduce or improve the original product as on (Ye et al., 2008; Zhang et al., 2024). This analysis can be carried out even when available information is limited, documentation is incomplete, or the manufacturer has intentionally withheld technical details, as in (Verim & Sen, 2023; P. Wang et al., 2021; Zivkovic et al., 2018).

One of the traditional coal mining companies in the Bayah subdistrict of Lebak relies heavily on the performance of its submersible pumps to support production. The pumps are installed in series; therefore, the failure of a single unit shuts down the entire production process. These pumps are used to remove water from depths of approximately ten meters to the surface, enabling mining operations to continue. The pumped fluid is not limited to water but also contains mud, gravel, and other suspended sediments. When activated, the motor drives the impeller, generating centrifugal force that draws the fluid upward as in (Melysa et al., 2021). The pump covers experienced severe corrosion after approximately one week of operation. Variations in fluid flow, particle impact on the pump surface, and exposure to naturally occurring acids in the mining environment accelerated corrosion. This deterioration led to the formation of holes in the pump cover, disrupting suction and preventing proper fluid transfer to the discharge pipes or hoses, as illustrated in Fig. 1.

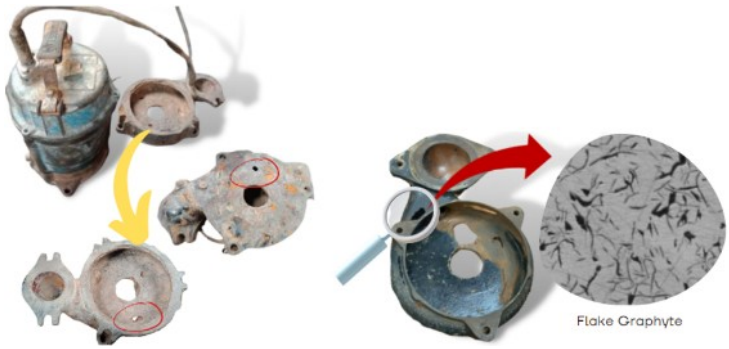


Fig. 1. Pump condition after 6x24 hours of use in a traditional coal mine

Products, components, or production machinery that experience damage or malfunction can have their service life extended through preventive maintenance. Preventive maintenance refers to scheduled and periodic activities that include inspection, repair, replacement, cleaning, lubrication, and adjustment, performed to maintain equipment reliability and prevent unexpected failures (Tsai et al., 2004; W. Wang et al., 2014). However, implementing preventive maintenance and routine inspections on submersible pumps used in mining and deep-well applications is challenging due to their limited accessibility. The pumps are located far below ground level, requiring considerable effort to reach them. Maintenance typically involves dismantling, during which the pump must be removed from the connected pipelines, as shown in Fig. 2. Consequently, mining operations must be halted, thereby increasing operational costs.

Previous reverse engineering (RE) processes for fluid machinery generally follow a workflow consisting of 3D scanning, CAD remodeling, optional simulation, and subsequent fabrication. This approach has been widely employed to digitize complex curved surfaces for redesign and rapid prototyping (Javaid et al., 2021). However, scan-to-CAD procedures still face challenges related to measurement accuracy, incomplete data acquisition, and limited flexibility in design modifications, which may lead to dimensional deviations and ambiguous feature reconstruction (Helle & Lemu, 2021; Klimecka-Tatar & Krynke, 2025; Onyia et al., 2025). In the pump sector, many studies integrating RE and AM have primarily focused on demonstrating the feasibility of replicating components typically found in impeller products and reporting that AM-manufactured components can match or even improve baseline performance.

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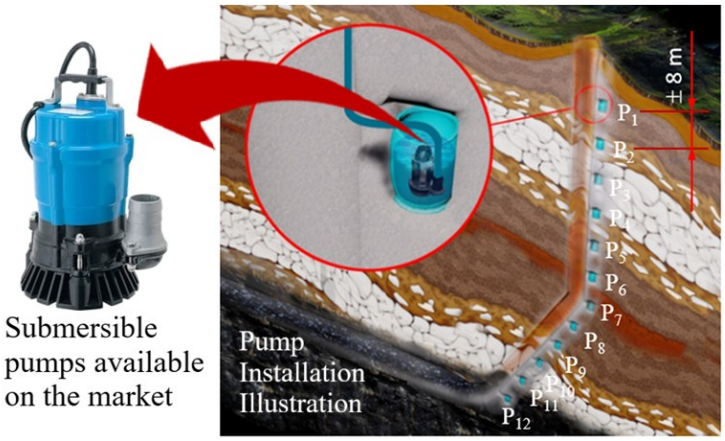


Fig. 2. Illustration of pump installation in mining and deep wells

Nevertheless, validation is often limited to realistic abrasive and corrosive slurry environments, and considerably less attention has been devoted to casing or cover components, in which erosion–corrosion is a major failure mechanism (Ponticelli et al., 2021). Accordingly, a clear research gap remains in the development of a comprehensive and experimentally validated RE framework that: (i) reconstructs an accurate pump cover geometry with traceable metrological verification; (ii) integrates design modifications aimed at improving durability; and (iii) verifies performance using AM-manufactured components under representative service conditions. To address this gap, the present study proposes an integrated workflow combining RE, 3D scanning, AM, and experimental validation for a submersible pump cover. The study delivers: (1) a validated digital model for redesign purposes; (2) an AM-based cover (or prototype) with quantified geometric fidelity and manufacturability; and (3) experimental evidence of improved service life and functional performance. These contributions provide practical guidance for rapid remanufacturing and durability enhancement of slurry-exposed pump components.

2. Method

The product development process is a series of steps companies use to conceptualize, design, and commercialize a product (Page et al., 2007; Ulrich et al., 2020). In this study, product development is conducted using RE techniques, as in (Saiga et al., 2021), which discusses the complete process of reconstructing and analyzing a component without the original design data, including geometry, materials, durability, manufacturing processes, data analysis, and performance (Liu & Wang, 2011; Yang et al., 2026). RE enables the analysis of existing products or components to understand their design, function, and characteristics, and to develop new products or improve existing ones (Fan et al., 2022; López & Vila, 2021; Maurya, 2019; Verim & Sen, 2023; Yao, 2005). The RE activities for the development of the pump cover product were carried out through several sequential stages, namely: (1) clarify and define the task, (2) 3D scanning, (3) CAD modeling, (4) manufacturing process design, (5) redesign and development, (6) finite element and flow simulations, (7) prototyping, and (8) field testing, as illustrated in Fig. 3.

This stage begins by identifying opportunities from existing problems. The study involves establishing the rationale for product development and describing the product and its specifications. The objective is to obtain an initial understanding of the product and gather the relevant information required for further improvement. The HS2.4S-53 submersible pump model produced by Tsurumi Pump has shown significant corrosion-related degradation after approximately 6×24 hours of operation, resulting in holes forming on the pump cover. These leaks hinder suction because the pump cannot generate sufficient lift, resulting in continuous water loss. At this stage, observations are also conducted to identify customer needs and expectations.

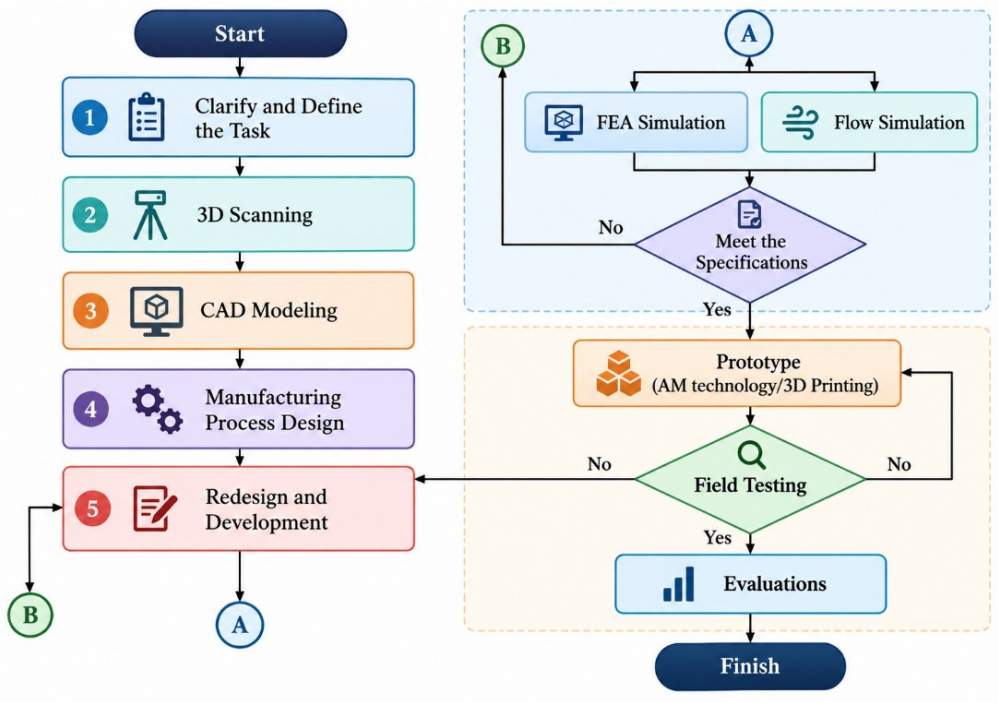


Fig. 3. Flowchart of RE cover pump process stages

The Demands (D) and Wishes (W) were systematically formulated to align with the company's operational requirements through consultations with its representatives. The geometric parameters were defined in accordance with the pump product specifications and corresponding performance standards. With respect to material selection, the company imposed no specific constraints; however, enhanced corrosion resistance to ensure extended service life was identified as the primary requirement. These aspects are summarized in Table 1.

Table 1. List of demands (D) and wishes (W)

D/W	Requirements
	Geometry
D	Outer diameter of the mating impeller housing: ø138 mm
D	Output hole diameter: 40 mm
D	Addition of nipple feature
W	Easy to install
W	Does not reduce aesthetics
W	Thickness adjusts to the manufacturing process.
	Material
D	Wear and corrosion resistant, with 100% increased service life over existing products
W	Easy to get and ergonomic
	Operational Capability
D	Operating 24 hours/day
D	The resulting discharge is not less than 0.2 m^3/min
	Application
W	Can be used in coal mines
W	Can support the process of waste processing
	Production
W	Can be mass-produced or individually

The product development stage was initiated based on an existing pump cover component. Owing to the unavailability of technical drawings and digital models, the geometric data of the existing

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component were acquired using 3D scanning technology to enable accurate model reconstruction. The activities include disassembling the product, scanning the current design, developing the product architecture, evaluating manufacturing considerations, comparing the original product with proposed modifications, and generating an alternative design (Akerdad et al., 2023; Fan et al., 2022; López & Vila, 2021).

To accelerate the development cycle, the existing product is digitized using 3D scanning technology. This approach enables the rapid creation of a digital model that can be re-modeled and exported for subsequent geometric data acquisition, as in (Zürn & Dieterle, 2024), which examines how reverse engineering can improve the recyclability and circularity of PLA cups by identifying process steps that require modification. The process consists of scanning, point-cloud noise reduction, and re-modeling, as illustrated in Fig. 4. The scanning was carried out in the reverse engineering laboratory of the Manufacturing Design Engineering Department using an ATOS GOM scanner with a resolution of 0.05 mm and an accuracy of 0.02 mm. The scanned point cloud data were processed and converted into an editable CAD model using GeoMagic. The edited CAD model served as the foundation for the redesign and development of the pump cover. This process was conducted using SolidWorks. The redesign and development process were carried out with consideration of the requirements and constraints of the selected manufacturing process.

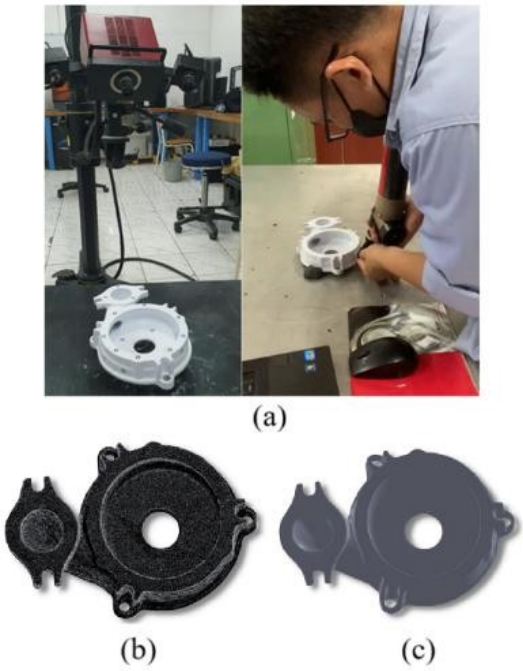


Fig. 4. Three-dimensional scanning technology: (a) scanning & measuring process, (b) point processing results, (c) remodeling

After the pump cover design was finalized, the next step was to conduct finite element analysis (FEA) and flow simulations. Both simulations were performed using SolidWorks. In the FEA stage, PA6 was selected as the material, and the boundary conditions were defined by applying fixture constraints to the contact surfaces where the pump cover is attached to the pump body, representing fixed supports. Contact interactions were modeled at the interface between the upper and lower snap-fit sections of the cover, using a no-penetration condition and a friction coefficient of 0.6 for PA6. Additional connections were assigned to the three bolt holes that secure the pump cover to the pump body and the strainer stand. A uniform internal pressure load of 0.1 N/mm2 was subsequently applied to the entire inner surface of the pump cover. To ensure the reliability of the simulation results, a convergence test was performed using the maximum displacement across all design alternatives. The mesh size was systematically varied from 10 mm to 2 mm to evaluate mesh sensitivity and confirm

solution stability. The simulations were performed using the Direct Sparse solver available in SolidWorks Simulation, as seen in Fig. 5.

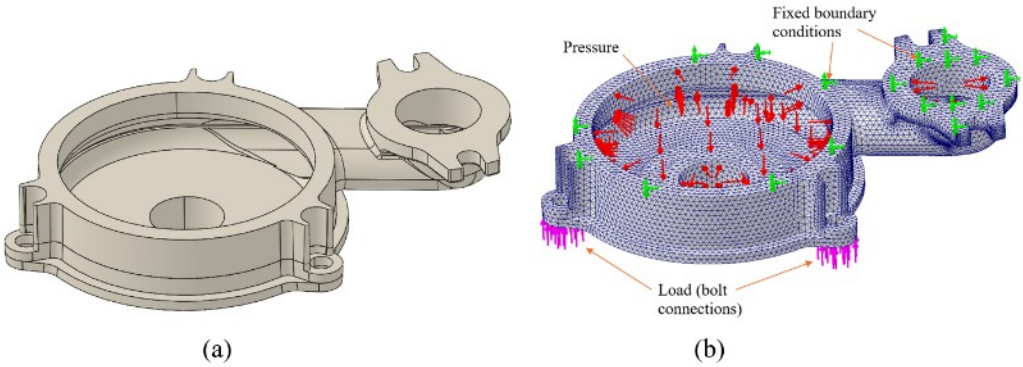


Fig. 5. FEA simulation: (a) FEA model, (b) Boundary condition and meshing

The redesign and development of the pump cover may necessitate modifications to the internal fluid-passage geometry, primarily to achieve a more uniform wall-thickness distribution. Such modifications are expected not to reduce the existing product's minimum flow capacity, which is 0.2 mm^3/min. To verify this requirement, a flow simulation was conducted, with the outlet volume flow rate as the governing parameter.

If the simulation results satisfied the specified criteria, a prototype was fabricated using additive manufacturing (AM) technology. To ensure the 3D-printed prototype matches the 3D model, a comparison is performed using Geomagic Qualify. Next, field testing is carried out to evaluate product performance. The field testing was conducted at a conventional coal-mining site in Bayah City.

3. Results and Discussion

3.1. Design Result

The point cloud data obtained from the scanning process was subsequently processed to generate a 3D CAD model, as illustrated in Fig. 6. This model served as the reference for the redesign and development of the pump cover.

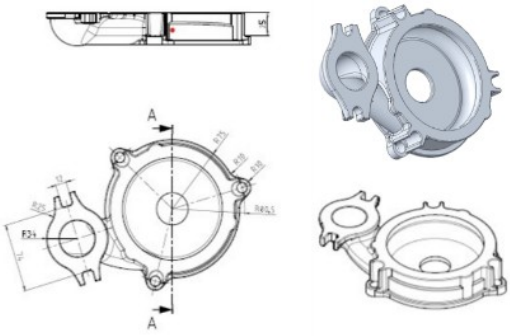


Fig. 6. CAD model generated from the 3D scanning process

Based on the CAD model shown in Fig. 6, the redesign and development stage were subsequently conducted by proposing several alternative design concepts. Alternative product design concepts are considered by focusing on potential manufacturing process selections using the PRIMA Process Information Maps (PRIMAs) method Myszka (2012), namely gravity casting of nickel alloys and injection molding of thermoplastic materials for medium- to high-volume production. This study focuses on the manufacturing process based on an injection molding system. To enable injection molding, the pump cover was divided into two components, a change from the original product

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configuration. The resulting product designs, comprising three proposed alternatives, are presented in Fig. 7. The three alternative pump cover designs were subsequently examined and evaluated in detail to identify the most suitable option, which was then further refined.

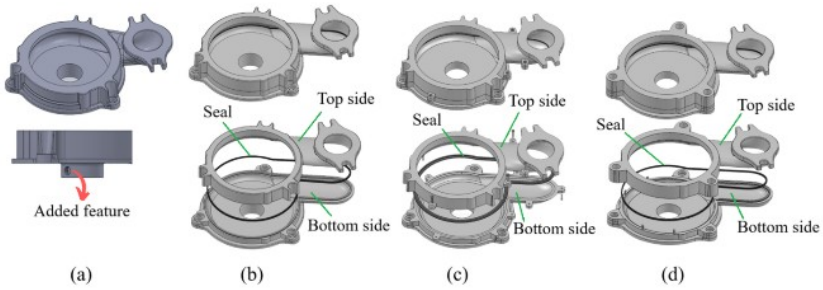


Fig. 7. Cover pump design concept: (a) design for the gravity casting process, and design for the injection molding process, (b) alt.1, (c) alt.2, (d) alt.3

The pump cover consists of two separate parts to accommodate the injection mold's core and cavity, as described by (Čechmánek et al., 2023; Kazmer, 2007; Menges et al., 2013). Therefore, it is necessary to consider how these two parts will be assembled. Several fastening alternatives for joining the two pump cover sections during assembly were proposed, including an annular snap-fit mechanism, bolt fastening, and a combination of annular and cantilever snap-fit mechanisms, as illustrated in Fig. 8. This assembly process is expected to be easy to perform and will not affect the components' expected function. All alternative designs for the upper and lower pump cover components were evaluated through FEA and flow simulations.

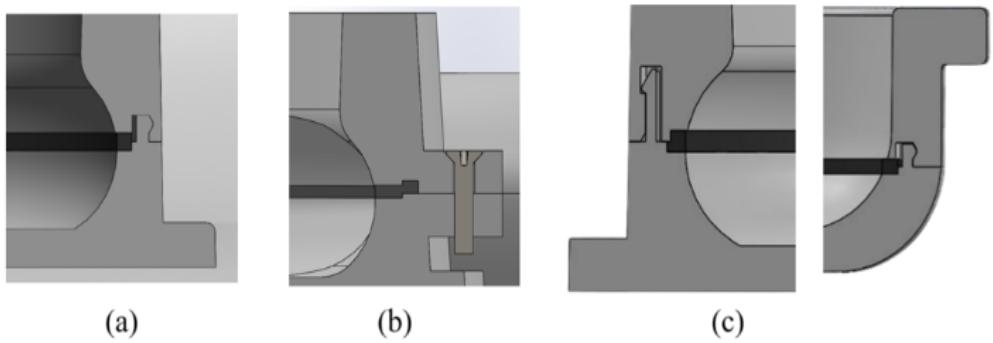


Fig. 8. Alternative fastening of the pump covers: (a) annular snap-fit, (b) bolt fastening, (c) combination of annular and cantilever snap-fit

3.2. Simulation Results

In the preprocessing stage, the material properties and boundary conditions were defined. The component was modeled using Polyamide 6 (PA6). A fixed boundary condition was applied to the upper surface of the pump cover to represent its constrained condition during service. Contact interactions between the upper and lower snap-fit features were modeled using a no-penetration contact formulation with a friction coefficient of 0.6, which represents the typical frictional behavior of PA6–PA6 interfaces. The bolt force for fastening the cover is modeled using a minimum normal force of 200 N.

An internal pressure load of 0.1 N/mm2 was uniformly applied to the entire internal surface of the component, incorporating a safety factor of 1.5 to account for operational uncertainties. Mesh convergence analysis demonstrated a stable, consistent solution trend at a global element size of 3 mm, indicating sufficient discretization accuracy for the deformation assessment. The deformation

conditions for each alternative are shown in Fig. 9. A comparison of the deformation conditions for the three alternative designs is shown in Table 2.

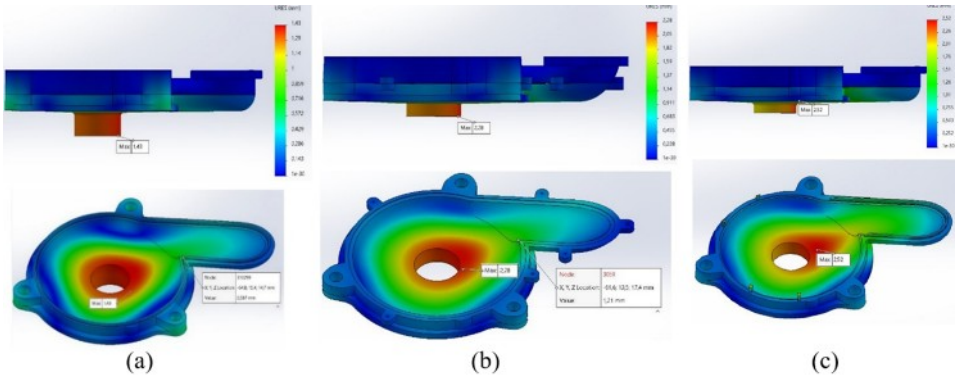


Fig. 9. Max displacement; (a) alt.1 using annular snap-fit, (b) alt.2 using bolt fastening, (c) alt.3 using a combination of annular and cantilever snap-fit

Table 2. Comparison of deformation conditions

Assembly type	Max. disp. [mm]
Annular snap fastening (Alt. 1)	0.75
Bolt fastening (Alt. 2)	2.28
combination of annular & cantilever snaps (Alt. 3)	2.52

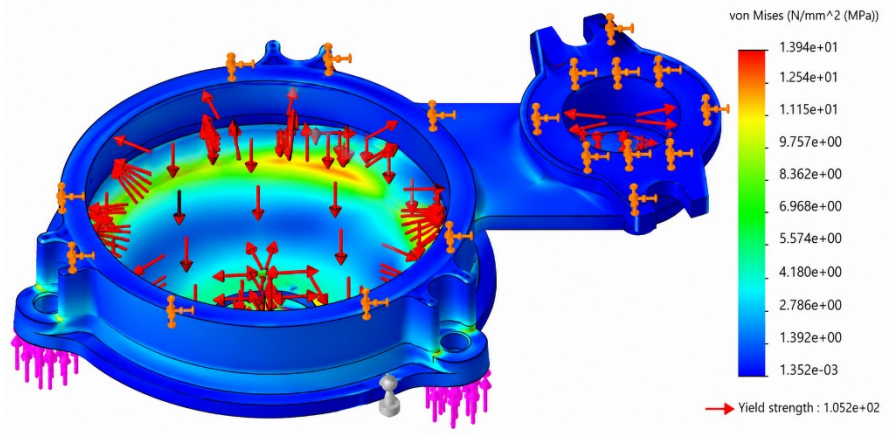


Fig. 10. Von Mises stress conditions for the pump cover

Most areas of the component are shown in blue, indicating relatively low von Mises stress. Higher stress values appear at the inner corners, geometric transition regions, around the bolt holes, and at the connection between the main cover and the side section. Stress concentration is observed at the wall intersection due to changes in geometry and cross-sectional area. The maximum stress value of 17.56 MPa is still far below the material yield strength of 103.6 MPa; therefore, the component remains within the elastic region and does not undergo plastic deformation in Fig. 10. Based on the calculated safety factor, the design can be considered safe against failure under the modeled loading conditions. However, the regions with the highest stress still require attention, particularly around the fillets, bolt holes, and wall transitions. If the component is subjected to repeated loading, fluid pressure, impact loading, or uneven bolt tightening, these areas may become potential initiation sites for cracks or local deformation. From a design perspective, increasing the fillet radius and providing sufficient local wall thickness can help reduce stress concentration. The development and modifications carried out must

not reduce the existing product's minimum flow rate by 0.2 m3/min. The flow rate of the modified product is calculated using flow simulation analysis. The selected parameters are the volumetric flow rate at the output. The simulation data shows that the water flow rate at the output is 0.2 m3/min. This indicates that the primary flow rate requirement has been met, as shown in Fig. 11.

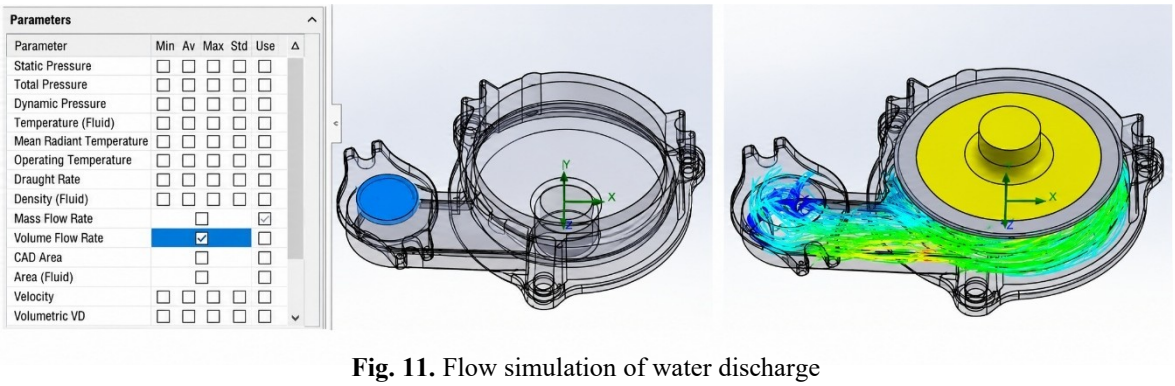


Fig. 11. Flow simulation of water discharge

Furthermore, the various alternatives are evaluated based on functional assessment, strength, manufacturing process, assembly process, additional work, and other factors, as shown in Table 3. Based on the assessment, the selected concept is a product with an annular snap fastening, namely alt.1.

Table 3. Alternative assessment

No	Assessment Aspects	weight value (%)	Alt 1		Alt 2		Alt 3	
			Value	Total	Value	Total	Value	Total
1	Function	30	4	120	4	120	1	30
2	Strength	20	4	80	3	60	1	20
3	Manufacturing process	15	3	45	3	45	3	45
4	Assembly process	15	3	45	3	45	3	45
5	Additional work	10	4	40	2	20	4	20
6	Aesthetics	10	4	40	2	20	4	20
Total			370		310		135	

To ensure the proposed product design can be manufactured via plastic injection molding, a conceptual mold design was developed. The mold concept consists of an active core–cavity construction for both the upper and lower pump cover components, as illustrated in Fig. 12.

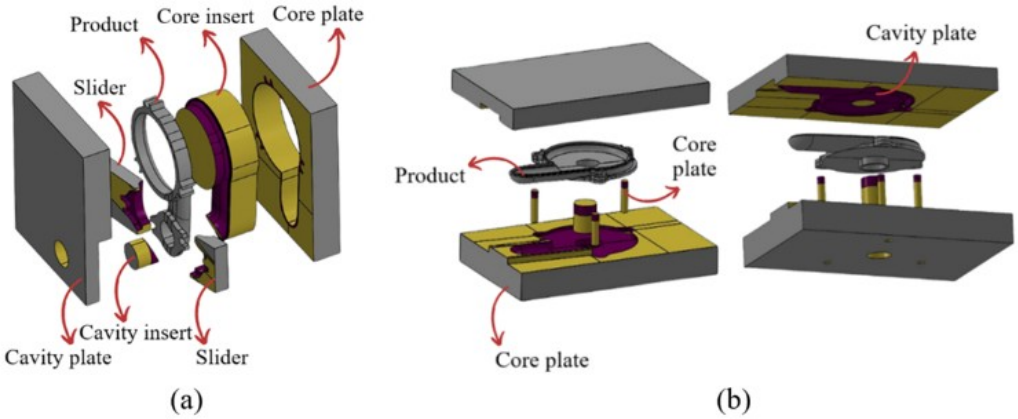


Fig. 12. Core and cavity opening design, (a) for the top product, (b) for the bottom product

3.3. Prototype Result

The prototype models consisted of two pump-cover designs: a single-piece design intended for casting and a two-piece design intended for injection molding. The CAD models were converted into STL format and subsequently transferred to the 3D printing machine. The prototypes were fabricated using Rigid Resin 4000 due to its availability at the RE Polman Bandung laboratory, as shown in Fig. 13 for a single-piece submersible pump cover and Fig. 14 for A two-piece submersible pump cover.



Fig. 13. A single-piece submersible pump cover product printing process

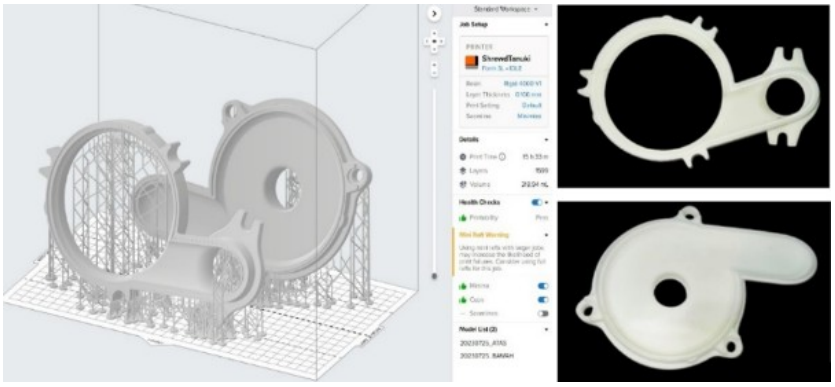


Fig. 14. A two-piece submersible pump covers the product printing process

The application of AM technology to assembled products often encounters the challenge of non-uniform shrinkage. During the assembly process, misalignments at several locations on the printed parts can prevent a proper fit. To identify these shifts or displacements, the printed components were 3D-scanned and compared with the original CAD model to quantify the resulting geometric deviations, as shown in Fig. 15.

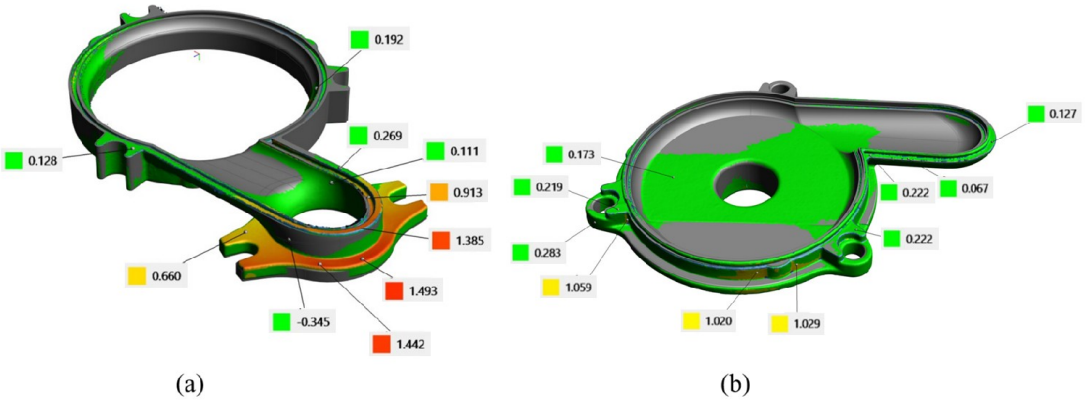


Fig. 15. Dimensional deviation between the 3D-printed part and the nominal CAD model: (a) top side, (b) bottom side.

Shrinkage occurs unevenly across various points on a prototype product. This aspect needs further consideration when using 3D printing technology. This 3D comparison method is limited to only identifying deviations in prototype products. Determining and concluding the shrinkage value is challenging because the current product shrinkage is volumetric (Marqués et al., 2024). To determine shrinkage values effectively and scientifically, further analysis and research with specific specimens are required to achieve greater precision. The comparison between the pump cover CAD model and the 3D-printed model for both the upper and bottom sides reveal dimensional deviations at several locations. These discrepancies may be attributed to global shrinkage or local distortion influenced by material contraction, printing parameters, and post-curing effects. Attention should be given to the mating regions between the two components. In these critical areas, the deviation ranges from a minimum of 0.11 mm (top side) and 0.07 mm (bottom side) to a maximum of 1.39 mm (top side) and 0.22 mm (bottom side). Assuming an overall shrinkage in the range of 0.3–0.5%, most mating regions remain within an acceptable limit. However, a localized deviation of 1.39 mm exceeds the expected range and therefore requires post-processing (e.g., finishing) to ensure proper assembly. A relatively large deviation of up to 1.49 mm is observed in non-critical regions. This is likely due to variations in local wall thickness, which increase susceptibility to uneven shrinkage. This condition should be addressed through design modification, particularly by optimizing and homogenizing wall thickness to minimize distortion and dimensional inconsistency.

3.4. Field Testing

At this stage, testing was conducted to determine whether the product could achieve a longer service life when manufactured from plastic. The prototype was produced using Rigid 4000 Resin, an engineering-grade material reinforced with glass fibers to provide a very high modulus and a smooth surface finish. To verify the similarity in the material properties of PA6 and Rigid 4000 Resin, the material data are presented in Table 4. Testing was conducted at PT Betterindo Mulya Kencana, a mining company. The trial results for the plastic submersible pump cover have shown no issues to date over the past 6 months. This indicates that replacing the metal material with plastic successfully extended the pump's service life, even surpassing the predefined performance target.

Table 4. Comparison of Rigid 4000 Resin and PA6

Properties	Rigid 4000 Resin*	PA6**
Tensile strength	69 MPa	98 MPa
Tensile modulus	4.1 GPa	5.7 GPa
Elongation at break	5.3%	5%
Flexural modulus	3.4 GPa	5.2 GPa
Flexural strength	105 MPa	140 MPa

Source: * Formlabs (2020); **(Ensinger)

Based on testing at the PT Betterindo Mulya Kencana, no complaints have been reported for approximately six months. This indicates that replacing metal with plastic material has successfully reduced corrosion, thereby increased the pump's lifespan and met the primary requirements. Second, the primary requirement for adding a nipple feature has also been met with the Misumi NPW 1 type, as can be seen in Fig. 16.

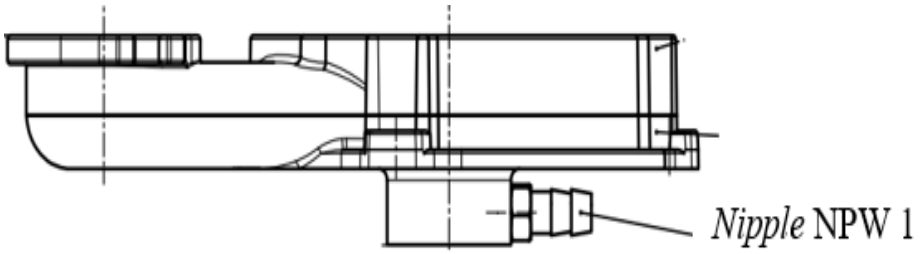


Fig. 16. Addition of nipple feature on the pump cover

Another primary requirement is the ability to operate continuously for 24 hours per day, as confirmed in previous tests. In addition, the key geometric features must be maintained, particularly the mating surface of the pump cover that interface with the upper pump and the overall external dimensions. These features are critical to ensure proper pump installation. The relevant dimensions, ∅ 138 mm and ∅ 40 mm, are shown in Fig. 17. These dimensions must match those of the existing product to avoid any adverse effects on the water discharge performance.

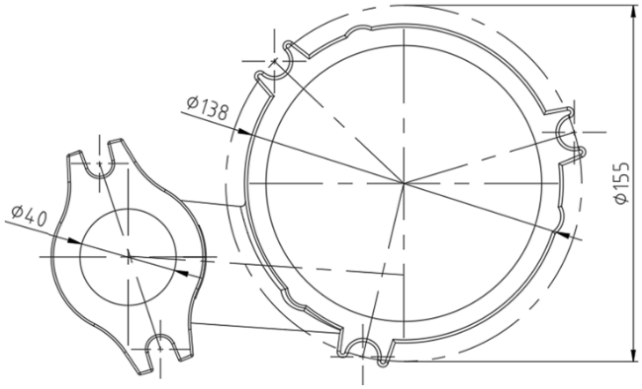


Fig. 17. Primary dimensions

Secondary demands of this development include quantity, assembly, and appearance. The product is expected to be produced either in mass or individually. If the product is to be mass-produced, injection molding is the preferred manufacturing process; for limited production, AM technology can be used. The product is also expected to be easy to assemble, and its snap feature simplifies installation. In addition to the assembly aspect, the selected product also does not compromise the aesthetics of the existing product; unlike the bolt alternative, it adds no additional features to the outer surface. This annular bond can be disguised because the bond is in the natural part of the product, as seen in Fig. 18.

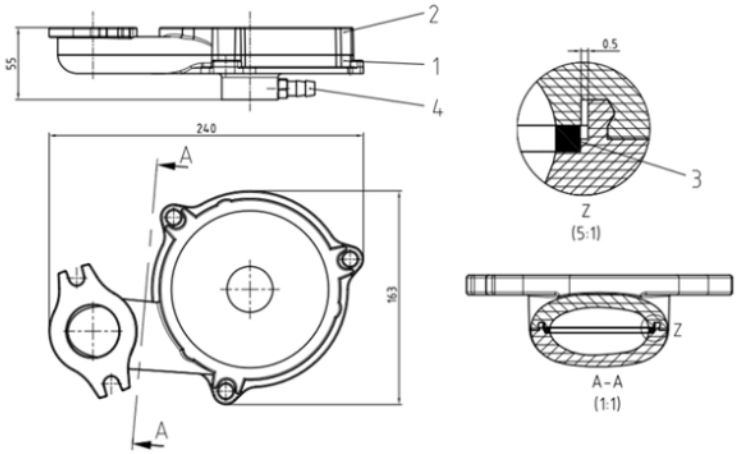


Fig. 18. Engineering documentation: (1) bottom pump cover, (2) top pump cover, (3) seal, (4) nipple

The results of this study are coherently integrated across the design, simulation, prototyping, and field-testing stages to ensure methodological consistency. The design phase, based on reverse engineering and design-for-manufacturing principles, established the geometric and functional improvements of the pump cover. CFD and FEA simulations were then conducted to evaluate the pressure distribution and structural strength, confirming that the redesigned model met the mechanical performance requirements and identifying critical stress regions (Arvianto et al., 2025; Kurnia et al., 2025). The SLA prototype using Rigid 4000 Resin enabled validation of dimensional accuracy and

shrinkage behavior. Observed deviations were consistent with global shrinkage and local distortion effects, particularly in areas with non-uniform wall thickness. Field testing further confirmed the redesigned cover's functional reliability and extended service life under actual operating conditions. Overall, the strong consistency among the design methodology, numerical simulations, prototype validation, and field performance demonstrates that the research findings are systematically presented, logically integrated, and sufficiently substantiated, thereby providing an effective solution to the identified industrial problem.

4. Conclusion

This study developed and validated a redesigned pump cover to improve service life and functional performance under harsh operating conditions. The substitution of the original material with a polymer-based solution was experimentally evaluated through prototyping using Rigid 4000 Resin fabricated via SLA additive manufacturing. Field testing demonstrated that the redesigned cover achieved an operational lifetime of approximately six months, representing a significant improvement over the previous configuration. Dimensional evaluation of the CAD model and the printed prototype revealed deviations attributable to global shrinkage and local distortion, particularly in regions with non-uniform wall thickness. While most mating areas remained within acceptable tolerances, localized deviations required minor finishing to ensure proper assembly. These findings highlight the importance of accounting for shrinkage behavior and geometric uniformity during the design stage.

From a manufacturing perspective, the study further translated the validated prototype into a mass-production design suitable for injection molding. Design modifications were introduced to improve manufacturability, particularly to facilitate part ejection from the core and cavity. The product was reconfigured into two components connected through an annular snap-fit mechanism. PA6 was selected as the candidate material for injection molding due to its mechanical characteristics being comparable to those of Rigid 4000 Resin and its suitability for high-volume production. Functionally, integrating a nipple as an oxygen supply channel enhances the system’s capabilities, enabling the component to operate not only as a transfer pump but also as an aerator that supports solids separation in wastewater applications. This dual-function feature constitutes an additional practical contribution to the study. The research contributes by integrating reverse engineering, additive manufacturing validation, dimensional accuracy assessment, and design-for-manufacturing considerations into a systematic development framework for pump components. For further optimization, additional mechanical locking features are recommended to improve assembly robustness. Future research should focus on the influence of non-uniform wall thickness on cooling behavior in injection molding, as uneven cooling may induce residual stress and dimensional instability. Therefore, optimizing wall-thickness distribution, cooling-channel configuration, and mold-temperature control are essential to ensure dimensional consistency and structural reliability in large-scale production.

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