A Validated Industrial Case Study Demonstrates a Practical Maintenance Intervention for Centrifugal Pump Mechanical Seals Under Supply-Chain Constraints

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ABSTRACT

Mechanical seal failure is a significant cause of unplanned downtime in centrifugal pumps used in large water and process industries, particularly where reliance on imported original equipment manufacturer (OEM) spare parts results in extended procurement lead times. This paper presents an industrial case study on the emergency in-situ restoration of a damaged stationary ceramics mechanical seal face in an ultrafiltration (UF) backwash pump (Tag: 50-P-007B, capacity 1100 m³/hr) at Dangote Fertiliser Limited, Nigeria. Following seal face chipping and the unavailability of replacement components with OEM lead times of 6–18 weeks, an epoxy-based composite material (M-Seal) was used as a contingency repair. The repair methodology involved controlled surface preparation, epoxy composite application to rebuild the sealing interface, finishing to restore functional flatness, and a monitored 24-hour curing period before recommissioning. On start-up, leakage ceased completely within minutes of operation. The pump was subsequently monitored under normal UF backwash operating conditions. Field evidence confirms that the repaired seal remained in continuous service for over four years without observable leakage, abnormal wear, or performance degradation. A comparative economic assessment indicates substantial reductions in downtime duration and maintenance cost relative to OEM seal replacement. The study demonstrates that controlled epoxy-based restoration of stationary mechanical seal faces can provide a reliable and cost-effective contingency maintenance strategy for benign water-based services, enhancing equipment availability and operational resilience under supply-chain constraints.

Keywords: Mechanical seal, centrifugal pump, epoxy composite, UF backwash, reliability engineering.

INTRODUCTION

Centrifugal pumps are critical assets in fertilizer, oil and gas, petrochemical, chemical, and water treatment facilities [12], [13], particularly within raw water treatment and ultrafiltration (UF) systems, where consistent flow and pressure are essential for stable operation. In UF installations, backwash pumps play a vital role in maintaining membrane performance by preventing fouling and sustaining treatment throughput. Any unplanned downtime of these pumps can adversely affect membrane integrity, reduce system availability, and necessitate operational workarounds that compromise process efficiency.

Mechanical seals provide a dynamic barrier that prevents process fluid leakage along the rotating shaft while maintaining acceptable levels of frictional heating and wear [1], [2].. Despite operating in relatively benign water-based services, mechanical seals remain one of the most frequent failure points in centrifugal pumps. Seal damage or leakage can lead to unplanned shutdowns, safety hazards such as slips and electrical risks, environmental exposure, and increased maintenance costs. Similar centrifugal pump and mechanical seal configurations are widely used across oil and gas facilities, including produced-water treatment units, seawater lift systems, gas processing plants, refineries, petrochemical complexes, liquefied natural gas (LNG) facilities, and offshore installations, where seal reliability is directly linked to production uptime, safety, and environmental compliance.

Conventional industrial practice dictates that damaged mechanical seal components be replaced with original equipment manufacturer (OEM) or equivalent parts in accordance with API 682 and ISO standards [1], [2], [3]. However, in many industrial environments, particularly in developing economies, spare-part availability is constrained by extended procurement lead times, logistical challenges, or limited onsite inventory. For high-capacity UF backwash pumps, such delays can result in prolonged downtime with significant operational and economic consequences [5], [15].

In response to these constraints, this paper presents an industrial case study documenting the in-house restoration of a chipped stationary ceramic mechanical seal face using a readily available epoxy-based composite material (M-Seal) [25]. The work represents an award-winning maintenance innovation and contributes to the literature by providing: (i) a repeatable and controlled repair methodology, (ii) long-term field performance evidence exceeding four years of leakage-free operation, (iii) a quantified economic comparison with OEM seal replacement, and (iv) a risk-based framework, including a mitigation matrix, to guide safe and responsible application. The study demonstrates a practical contingency maintenance strategy for benign water-based services, where equipment availability is critical and supply-chain resilience is limited.

Background and Problem Description

Mechanical Seal Fundamentals and Field Practice

Mechanical seals rely on a pair of precision faces, one rotating and one stationary, maintained in controlled contact through spring force and hydraulic pressure. Performance is governed by face flatness, surface finish, material compatibility, and a stable lubrication film [7], [18]. In water-based applications, stationary faces are often ceramic due to their self-lubricating behavior, hardness, and tolerance to occasionally dry running.

Common failure modes include face chipping, scoring, thermal cracking, blistering, and distortion arising from misalignment, abnormal vibration, or operational upsetting [17], [19]. Field maintenance strategies typically differentiate between corrective replacement and controlled refurbishment. Refurbishment may involve lapping, re-facing, or selective replacement of damaged elements when partial spares are available. In emergency scenarios, polymer-based composites are occasionally used to restore sealing surfaces in low-temperature, non-abrasive services. However, published evidence of long-term, leakage-free performance for polymer-restored ceramic seal faces, particularly in large, continuously operating centrifugal pumps, is limited [25], [29]. This case study addresses this gap by documenting extended field performance and providing a structured risk and economic assessment.

UF Backwash Pump Duty and Operating Conditions

The study focuses on UF Backwash Pump 50-P-007B, part of a two-working, one-standby arrangement for ultrafiltration permeate backwash. The pump is a horizontal centrifugal design with an axially split casing, rated at approximately 1100 m³/h at 50 m total differential head (TDH), operating at 1488 rpm and driven by a 250 kW ABB motor with variable-frequency drive (VFD) control. The pumped fluid is UF permeate with a density near 1000 kg/m³ and typical operating temperatures ranging from 22 to 34 °C (design temperature up to 65 °C). Key parameters are summarized in Table 1.

The mechanical seal is a single, unbalanced, API 682–referenced configuration with a stationary ceramic face [1]. The pump operates continuously under outdoor conditions, supporting periodic backwash and chemical-enhanced backwash cycles to sustain membrane performance. Maintaining uninterrupted operation is critical to prevent fouling, preserve membrane integrity, and avoid operational workarounds that could reduce overall treatment efficiency.

Table 1: Summary of key UF Backwash Pump parameters (paraphrased from OEM datasheet).

Parameter	Value (from datasheet)	Notes
Pump tag	50-P-007 A/B/C (case: 50-P-007B)	UF Backwash Pump Set

Type	Horizontal centrifugal, axial split casing	Single stage
Rated flow	≈1100 m^3/h	BEP ≈1150 m^3/h
TDH	≈50 mWC	Shut off ≈58 mWC
Speed	≈1488 rpm	50 Hz
Pump efficiency	≈86%	At the design point
Driver power	250 kW	ABB motor, VFD operated
Seal configuration	Single, unbalanced	API 682 referenced
Fluid	UF permeate	pH ~7.5–8.0

Fig 1. 50-P-007B UF backwash pump

Fig 2. Inspection of the chipped ceramic face

Seal Failure Mode and Constraints

During routine operation, leakage was observed at the seal gland region of Pump 50-P-007B, prompting controlled shutdown and dismantling. As shown in Fig. 1, Inspection revealed localized chipping of the stationary ceramic seal face, consistent with surface degradation and loss of effective sealing contact. The

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unavailability of immediate replacement components on-site, combined with OEM procurement lead times of 6–18 weeks, presented a significant operational constraint. Prolonged downtime threatened UF system availability, membrane health, and overall process continuity.

To mitigate these risks, an in-house restoration approach using an epoxy-based composite (M-Seal) was executed, providing a rapid return to service while maintaining acceptable safety and reliability standards. The intervention was formally recognized by plant management, underscoring its operational impact and validating the methodology within the facility.

MATERIALS AND REPAIR METHODOLOGY

Material Selection: Epoxy Composite (M-Seal)

Mechanical seal stationary faces in water-service centrifugal pumps are traditionally manufactured from ceramic due to their hardness, dimensional stability, and resistance to wear under hydrodynamic lubrication conditions [7], [18]. For this emergency restoration, a two-part epoxy-based composite M-Seal) was selected based on adhesion strength and compressive stability consistent with polymer composite design principles [24], [26], and compatibility with benign water-based service conditions.

While not inherently self-lubricating like ceramic, cured epoxy composites can provide sufficient compressive resistance and maintain a stable sealing surface in low-solid-content, near-neutral-pH, moderate-temperature UF permeate service. The objective of the repair followed structured reliability and workmanship controls consistent with reliability-centered maintenance (RCM) practices [15], [16] rather than to replicate all properties of the original ceramic face.

Table 2: Conceptual comparison of functional material properties between conventional ceramic seal faces and epoxy composite (M-Seal) restored stationary faces for water-based service

Property	Ceramic Seal Face (Conventional)	Epoxy Composite (M-Seal, Restored Face)
Primary function	Designed sealing and wear surface	Restored sealing surface
Self-lubrication	Yes	No (relies on fluid film)
Adhesion to substrate	Integral material	High (bonded to base material)
Thermal resistance	High	Moderate (service-limited)
Wear behavior	Controlled, predictable	Low wear in benign service
Suitability for UF permeate	Excellent	Validated (this study, >4 years)

Tools and Consumables

The repair was performed using standard workshop consumables and personal protective equipment (PPE) as follows:

- Gloves, safety goggles, and solvent masks (as required)
- Cleaning solvents/degreasers and lint-free clothes
- Mixing pad and applicator for epoxy composite
- Straightedge and feeler gauge (or comparable instruments for flatness measurement)

- Fine abrasive paper and lapping plates for controlled finishing

Surface Preparation and Application

The repair followed a controlled, stepwise workflow to ensure reproducibility and reliability:

1. **Isolation and Dismantling**: The pump was isolated, electrically locked out, and the seal chamber dismantled according to standard safety procedures.

2. **Cleaning**: The stationary ceramic seal face and surrounding seat were thoroughly cleaned to remove oil, debris, and scale. Solvents were used as needed to ensure a contaminant-free surface.

3. **Surface Preparation**: The damaged region was gently roughened using fine abrasives to improve the mechanical adhesion of the epoxy. Care was taken not to alter critical fits or the geometry of the surrounding face.

4. **Epoxy Application**: M-Seal epoxy was mixed following the manufacturer's instructions and applied in thin, controlled layers to fully rebuild the chipped area. Air entrapment was minimized, and the surface was slightly overbuilt to allow subsequent finishing.

5. **Curing**: The restored seal face was allowed to cure under ambient conditions for a controlled period of 24 hours. The assembly was protected from vibration or disturbance during curing to prevent surface waviness or adhesion compromise.

6. **Finishing and Lapping**: After curing, the repaired surface was finished using fine abrasives and lapping to restore flatness and ensure a smooth sealing interface compatible with the rotating mating ring. Flatness was verified with a straightedge and feeler gauge.

7. **Reassembly and Verification**: The mechanical seal was reinstalled in the pump, ensuring correct alignment. The flush line and seal gland were inspected for cleanliness before starting up.

Overhauling UF Backwash Pump (50-P-007B) Activities For the Repair of the Broken Seal Face

Fig 3. Unboxing 50-P-007B top case cover

Fig 4. 50-P-007B bearings/ seal removal

Fig 5. Epoxy composite material

Fig 6. Mixing of epoxy composite material

Fig 7. Repaired the stationary mechanical seal face

Fig 8. Boxing up of the mechanical seal face

Figure 4: Presents a process map summarizing the workflow: Inspection → Overhauling → Surface Preparation → Epoxy Application → Curing → Finishing/Lapping → Reinstallation → Monitoring.

Technical Considerations

- The epoxy layer functions as a **stable sealing surface**, not a sacrificial wear element.
- The method is suitable for **benign, low-temperature, water-based fluids**; high-pressure or abrasive services are outside its validated scope.
- Flatness and adhesion are critical to long-term, leakage-free operation; hence, controlled lapping and strict curing adherence were enforced.

RESULTS AND PERFORMANCE EVALUATION

Commissioning and Start-Up Observations

Following reassembly, the repaired pump was subjected to a controlled commissioning and trial run sequence to ensure safe return to service [9]. The commissioning workflow included: verification of seal chamber cleanliness, confirmation of flush path availability (API Plan 11), alignment checks, staged ramp-up to operating speed, and observation of pump vibration and bearing temperature relative to baseline.

During the initial start-up, minor droplets were observed at the gland, indicative of residual surface wetting. These droplets ceased completely after approximately 3–5 minutes of continuous operation, confirming that the epoxy-restored stationary face had established a stable sealing interface. No abnormal vibration or temperature excursions were detected, and flush flow remained unobstructed, satisfying the predefined acceptance criteria [14], [16] summarized in Table 3.

Table 3. Initial Acceptance Criteria and Monitoring Triggers for Repaired Seal

Parameter	**Initial Acceptance Target**	**Ongoing Monitoring Trigger**
Visible leakage at the gland	None	Any recurring leakage
Vibration (overall)	Stable vs baseline	Sustained upward trend
Bearing temperature	Normal range	Persistent increase
Seal flush flow (API Plan 11)	Unobstructed	Restriction or contamination

The rapid cessation of leakage during commissioning demonstrated the functional effectiveness of the epoxy composite restoration and validated the surface preparation, application, and finishing procedures.

Long-Term Operational Performance

Following commissioning, the repaired stationary ceramic face remained in continuous service for over four years under normal ultrafiltration (UF) backwash and chemical-enhanced backwash (CEB) duty. Routine monitoring was conducted via operator visual inspections, vibration checks, and periodic maintenance observations. No persistent leakage, abnormal vibration trends, or seal flush restrictions were recorded during this period.

Minor spillage was observed only after extended service, which coincided with the scheduled OEM seal replacement, confirming that the epoxy restoration met or exceeded operational expectations over multiple service years. This long-term performance demonstrates that, in low-solids, near-neutral-pH, moderate-temperature UF permeate service, polymer-composite restoration can preserve sealing materials under benign aqueous conditions [18], [21], when workmanship controls, surface preparation, controlled curing, and finishing are strictly applied.

The results indicate that the dominant reliability requirement was maintenance of contact geometry and flatness of the sealing interface, rather than high-temperature or high-abrasion resistance. These empirical observations support the use of epoxy-based restoration as a practical contingency strategy for critical process equipment operating under spare-part constraints, providing extended leakage-free operation and reduced operational downtime.

Economic and Risk Assessment

Economic Impact and Downtime Avoidance

OEM replacement is typically associated with higher lifecycle cost and extended downtime [5], [6]. Reliability engineering models emphasize that downtime cost often exceeds material cost in critical process systems [15]. Figure 1 presents a structured comparison between conventional OEM replacement and epoxy-based in-house repair.

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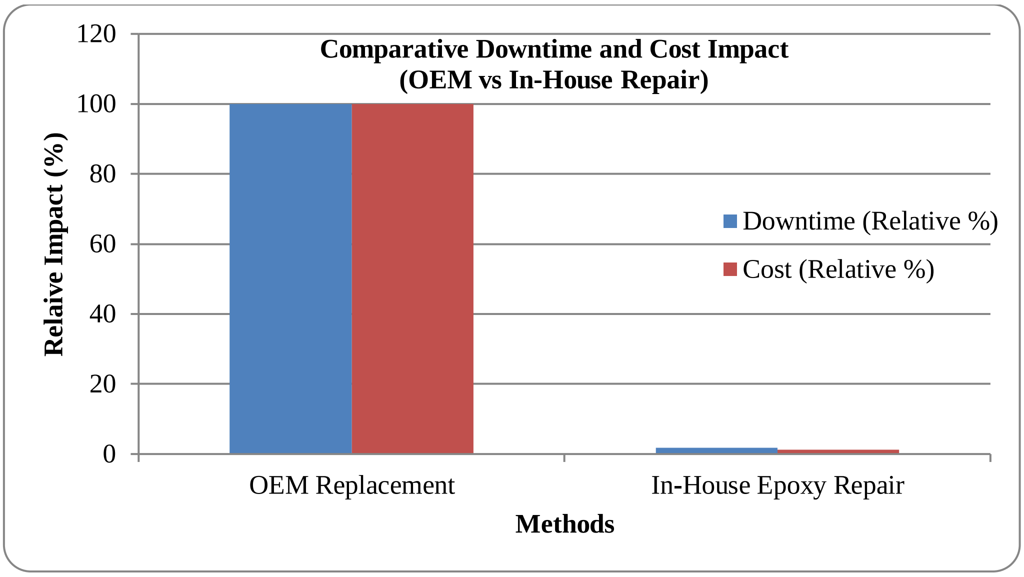

Fig 1. Economic and Availability Impact: OEM Replacement vs. In-House Epoxy Repair

The **largest cost driver** in industrial water treatment facilities is generally **downtime cost**, which can include lost production, membrane fouling, or process disruption. Even conservative estimates favor the rapid in-house restoration approach, provided that technical risks are adequately controlled.

Technical Comparison: OEM vs. Epoxy Restoration

Table 4 compares the two approaches from a technical and operational perspective. The in-house epoxy repair should be considered a contingency method for defined service conditions and is not a universal substitute for OEM components.

Table 4. Technical and Operational Comparison

Parameter	**OEM Replacement**	**In-House Epoxy Restoration (This Study)**
Design intent	Permanent repair using certified materials	Contingency restoration under constrained spares
Best-suited service	All specified services	Benign, water-based, low-solids duties
Quality control basis	OEM manufacturing QA	Workmanship QA: surface prep, curing, finishing, checks
Expected reliability	High and predictable	Validated high for this service (>4 years)
Cost and time	Higher cost (**₦1,800,000.54, - ₦2,182,069.27)** + longer lead time (6weeks – 18weeks)	Low cost (**₦15,000.00 - ₦35,00.00)** + rapid return to service (30hours – 48hours)
Operational risk	Lower	Requires a monitoring and mitigation plan

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Risk Assessment and Mitigation

The application of non-standard repair materials introduces specific technical risks, primarily associated with adhesion failure, loss of flatness, thermal degradation, and contamination. Figure 2 and Table 5 summarize a qualitative risk matrix and a simplified FMEA approach to guide safe implementation [15], [30].

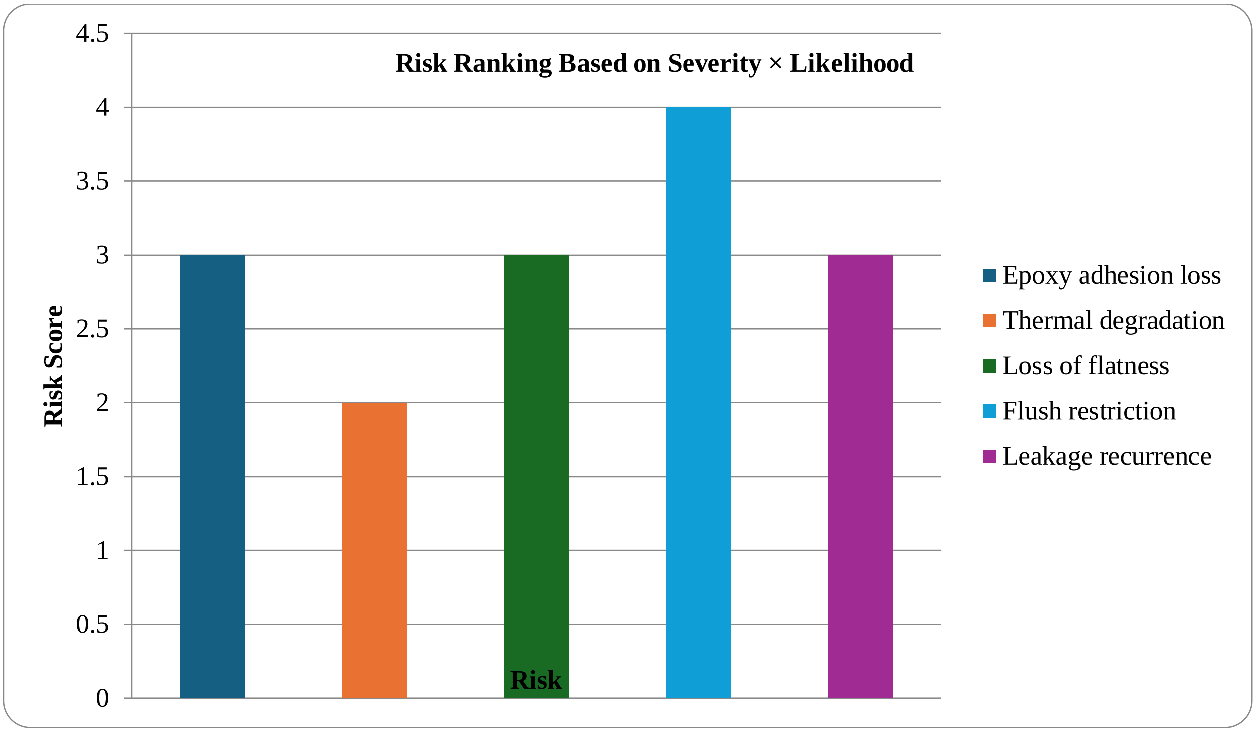

Fig 2. Qualitative Risk Matrix for Epoxy-Restored Ceramic Seal Faces

Table 5. Simplified FMEA for Epoxy-Based Stationary Face Restoration

Failure Mode	**Potential Effect**	**Likely Cause**	**Controls / Detection**	**Recommended Action**
Seal leakage	Loss of containment; downtime	Face distortion; poor finish	Visual checks; vibration trend	Re-lap surface; review cure/finish steps
Rapid wear	Reduced seal life	Solids ingress/abrasives	Flush inspection; filter checks	Restrict service to low-solids duties
Thermal crack	Leakage; face failure	Dry running; overheating	Temperature monitoring	Ensure flush; verify suction; avoid deadheading
Debonding	Sudden leakage	Poor prep; contamination	Early leakage signs	Repeat prep; consider OEM replacement if needed

Applicability Limits and Implementation Guidance

The repair methodology is suitable only for benign, water-based, low-solid, moderate-temperature services. Key implementation controls include:

- Confirm pump service conditions and seal type; ensure restoration does not alter critical fits
- Apply strict cleanliness and contamination control

- Use thin epoxy layers with full curing before finishing
- Perform controlled lapping to restore flatness and smooth sealing interface
- Conduct structured reassembly, flush verification, and staged start-up
- Document the repair and implement a routine monitoring plan (leakage checks, vibration trending)

DISCUSSION

Engineering Implications

The documented four-year leakage-free performance of the epoxy-restored stationary ceramic face demonstrates that, under carefully controlled conditions [24], [25], epoxy composites can provide durable and reliable sealing surfaces in centrifugal pumps operating with benign, water-based fluids. Key engineering factors contributing to success include:

a) **Surface preparation and flatness control:** Proper cleaning, gentle roughening, and controlled lapping ensured that the epoxy layer maintained a stable contact geometry with the rotating face, preserving sealing integrity.

b) **Curing stability:** Allowing a full 24-hour cure in a vibration-free environment minimized surface waviness and dimensional distortion.

c) **Operating envelope suitability:** The UF backwash service presented low solids content, near-neutral pH, and moderate temperature, reducing the thermal and abrasive demands on the restored surface.

d) **Monitoring and maintenance framework:** Structured commissioning, ongoing visual inspection, vibration trending, and flush flow checks provided early detection of potential issues and ensured continued performance.

From a reliability engineering perspective, the primary requirement was the preservation of contact geometry and interface stability, rather than replication of high-temperature, high-abrasion wear resistance typically associated with OEM ceramic faces. The intervention demonstrates that well-executed polymer-composite restoration can serve as a practical contingency strategy documented in maintenance engineering literature [29], in situations constrained by spare availability or extended procurement lead times.

Suitability for Similar Services

The approach is broadly applicable to low-solids, water-based centrifugal pump services where thermal, chemical, and abrasive stresses are limited. It is particularly advantageous in scenarios where:

- Downtime costs are high, and rapid return to service is critical.
- OEM seal components are subject to long lead times or logistical constraints.
- Service fluids are benign, reducing the likelihood of adhesion failure or thermal degradation.

The method should be implemented with strict workmanship controls cleaning, surface preparation, epoxy application, curing, and finishing, to ensure repeatable results. For broader adoption, facilities may integrate surface roughness (Ra) measurement, flatness verification using optical or dial-gauge methods, and post-repair vibration/temperature trending to strengthen process control and confidence in repair outcomes.

While the approach is not a replacement for OEM seals in high-temperature, abrasive, or chemically aggressive services, it provides a validated, low-cost, and rapid contingency solution that can significantly improve asset availability and reduce operational risk in critical process systems.

Recognition and Practical Value

The methodology's operational impact was formally recognized by plant management through a Certificate of Recognition and Performance Award, underscoring its practical value in industrial maintenance engineering. The extended leakage-free service life highlights the potential for indigenous engineering innovation to deliver sustainable solutions in environments with constrained supply chains, aligning with broader reliability-centered maintenance objectives.

CONCLUSIONS

This industrial case study demonstrates the **successful in-house restoration of a damaged stationary ceramic mechanical seal face** on UF Backwash Pump 50-P-007B using a two-part **epoxy composite (M-Seal)** in the absence of immediate OEM spare parts. The key findings and outcomes are summarized as follows:

a) **Long-term operational performance:** The repaired seal has remained leakage-free for **over five years** under continuous UF backwash and chemical-enhanced backwash (CEB) duty, validating the durability of epoxy-based restoration under low-solid, water-based service conditions.

b) **Engineering and reliability implications:** When applied with a **controlled workflow**, including cleaning, surface preparation, epoxy application, curing, and precision finishing, the method preserves critical seal geometry, providing stable sealing performance without premature failure. The approach functions as a **contingency reliability strategy** rather than a full replacement for OEM components.

c) **Economic and availability benefits:** Rapid restoration avoided extended downtime of **6–18 weeks** associated with OEM seal procurement, significantly reducing operational losses and lifecycle maintenance costs. Cost savings are maximized in situations where downtime consequences outweigh material costs.

d) **Risk and applicability considerations:** The technique is most suitable for **benign, water-based services** with moderate temperature and low abrasive loading. Structured **risk management and monitoring,** including visual leakage checks, vibration trending, and flush flow verification, are essential to ensure continued reliability.

e) **Practical value and replicability:** The intervention was formally recognized by plant management, highlighting the importance of **disciplined workmanship, process controls, and local engineering innovation**. Facilities can safely replicate the method using standardized work instructions, curing protocols, finishing checks, and post-repair monitoring logs.

RECOMMENDATIONS

- Restrict the method to low-stress, water-based services unless further validation is conducted.
- Develop and standardize controlled work instructions covering epoxy application, curing, and finishing.
- Implement a simple post-repair monitoring log tracking leakage, vibration, and temperature.
- Maintain a minimum inventory of critical seal spares to reduce reliance on emergency repairs.

Overall, the study confirms that **epoxy composite restoration can serve as an effective, low-cost, and rapid contingency solution** for large centrifugal pumps in water treatment processes, delivering both reliability and operational resilience.

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