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AN EXPERIMENTAL STUDY ON THE WEAR BEHAVIOR OF WATER-LUBRICATED ACM COMPOSITE BEARINGS AND PROPELLER SHAFT SYSTEMS UNDER SAND AND SEDIMENT IN LUBRICATING WATER

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Abstract
Water-lubricated composite bearings (WLCBs) are widely used in marine propulsion shaft systems because of their environmental compatibility, low maintenance requirements, and ease of replacement. Inland waterways often contain high concentrations of sand and sediment; therefore, dredging vessels, and vessels operating in shallow waters frequently experience abnormally rapid wear of propeller shaft bearings. This study presents field survey results on the wear behavior of ACM L2 Marine propeller shaft bearings and shaft journals. Ten vessels were inspected during dry-docking for bearing repair or replacement of propeller shaft bearings after 1.5-5 years of operation, in three operating environments: sea (clean water), estuary (water mixed with silt), and inland waterway/dredging vessels (water with a lot of sand and sediment). For each vessel, the authors assessed the overall wear condition, bearing surface and propeller shaft journal, and measured the lubrication clearance. After synthesizing the experimental data, two groups emerged: Group A, consisting of vessels operating in clean water, showed an increase in lubrication clearance of 0.13-0.16 mm/year, a value within the manufacturer's stated range; Groups B and C, consisting of vessels operating in water containing a lot of sand and sediment, showed an increase in lubrication clearance of 0.6-1.0 mm/year, which is up to six times higher than the manufacturer's specified value. Therefore, the lifespan of propeller shaft bearings in groups B and C was only about 1.5-2 years. The mechanisms causing rapid wear of propeller shaft bearings and propeller shaft journals were identified by the authors as follows: three-body wear (predominant in water containing a lot of sand and sediment), bearing surface peeling, and poor cooling water flow due to clogged water channels. The main causes were the lack of separate cooling water filtration systems in the vessels, and installation and operation errors. In addition to analyzing the causes, the authors have put forward five recommendations to extend the lifespan of bearings and shafts for inland waterway vessels and dredging vessels.

Keywords: *Maintenance, wear, propeller shaft systems, Water-lubricated composite bearings, dry-dock.*

1. Introduction

Water-lubricated composite bearings (WLCB) are gradually replacing oil-lubricated metal propeller shaft bearings due to their advantages of being environmentally friendly, convenient in maintenance and replacement, and low operating costs [1, 2]. ACM L2 Marine is a high load composite bearing material that has been specifically formulated for marine environment applications. It comprises synthetic fabric reinforcement impregnated with a thermosetting resin and solid lubricant fillers, with a low coefficient of friction (0.13 with stainless steel) [3].

However, water-lubricated propeller shaft bearings have a shorter service life and less stable operation than oil-lubricated metal bearings, because WLCBs are lubricated by externally supplied seawater, so the service life of the propeller shaft bearings will depend quite heavily on operating conditions and the quality of the cooling water. Sand, silt, and sediment particles are pumped into the propeller shaft bearings by the cooling water pump. At this time, the sand and sediment particles entering the propeller shaft bearing will act as abrasive particles, causing accelerated surface wear of the propeller shaft bearings and the propeller shaft journal surface, causing the lubrication clearance to increase much faster than expected during design [4, 5]. In

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Vietnam, it is estimated that about 100-130 million m³ of river sand is extracted annually [6] by a fleet of sand dredging vessels and shallow draft vessels operating continuously in inland waterways containing high sediment concentrations, including the Red River, Da River, Duong River and tributaries in the Mekong Delta...

While the wear rate of WLCB in clean water conditions has been clearly described [7-10], systematic field survey data from Vietnamese dry dock inspections in sand-containing environments is still very limited. This study addresses that gap by directly measuring bearing clearance and damage morphology on ten surveyed vessels, providing a quantitative basis for adaptive maintenance guidelines for vessels operating in inland waterways/dredging vessels.

2. Theoretical Basis

2.1. Lubrication Regime

The behavior of the bearing is regulated by the Sommerfeld number $S = \eta \cdot n \cdot (D/C)^2/P$ (η: viscosity; n: shaft speed; D: diameter; C: clearance; P: average pressure). Fully hydrodynamic lubrication requires sufficient speed to maintain a continuous water film. During low-speed manoeuvring and stop-start dredging operations, the system switches to mixed lubrication or boundary lubrication, greatly increasing wear. Abrasive particles entering the clearance during this transition cause the most serious damage [7].

2.2. Extended Archard Wear Model

The volumetric wear rate under three-body wear is expressed as follows:

$$v = K_{env}.K_0.W.\frac{L}{H} \quad (1)$$

Where K_0 is the Archard coefficient in clean water; *K_env* is the environmental coefficient taking into account particle concentration *Cs* (mg/L) and average size d_{50}; *W* is the load; *L* is the sliding distance; where *H* is the surface hardness. From published regression data [4, 5]:

$$K_{env} = 1 + 2{,}18.\left(\frac{C_s}{100}\right)^{0{,}61}.exp\left[-\frac{(d_{50}-175)^2}{2.95^2}\right] \quad (2)$$

Maximum abrasion acceleration occurs at $d_{50} \approx 175\mu m$ - the range of fine-medium sand common in Vietnamese river sediments. Integrating equation (1) gives the predicted life:

$$T = \pi.D.B.\Delta_{max}\frac{H}{2.K_{en}.K_0.W.v} \quad (3)$$

Where *D, B* are the shaft diameter and bearing length, *Δmax* is the allowable clearance limit and *v* is the sliding velocity.

3. Survey Methodology

3.1. Vessel Selection and Classification

Ten vessels equipped with ACM L2 Marine bearings were surveyed during dry-docking between 2020 and 2023, grouped by operating environment:

Group A (5 vessels) - Deep-sea: low turbidity, well-maintained cooling water.

Group B (2 vessels) - Estuarine/port: moderate seasonal turbidity; intermittent sand exposure.

Group C (3 vessels) - Inland/dredging: sustained high turbidity (*TSS>300mg/L*); continuous sand particle exposure.

Table 1. Overview of the survey fleet

Vessel	Type	Built	kW	Svc (years)
Giang Hai	Cargo	2018	2,200	3
Dong Ho	Cargo	2017	2,940	5
PTSC 05	Tugboat	2016	1,800	5
PTSC 07	Tugboat	2018	1,800	3
VSICO	Cargo	2019	3,310	3
Hoang Gia	Tugboat	2018	2×882	3
Lucky Star	Cargo	2019	735	3
Viet Thuan	Cargo	2020	4,410	2
Hai Duong	Dredger	2019	441	2
Thai Binh	pump	2022	-	0.5

3.2. Inspection Procedure

A standardised 5-step protocol was applied to each vessel:

(1) pre-disassembly documentation;

(2) bearing removal without chemical cleaning to preserve surface morphology;

(3) dimensional measurement - bore diameter at 3 axial positions × 2 orthogonal planes (Mitutoyo 511-series bore gauge, 0.01 mm resolution); shaft journal at 6 corresponding positions (Mitutoyo MDC-25PX micrometer, 0.001 mm);

(4) surface characterisation - Ra at 5 locations per bearing (Mitutoyo SJ-210, ISO 4288) and macro

photography at 8-15× magnification;

(5) operational records review.

4. Survey Results

4.1. Group A - Deep sea: Normal Wear

All five Group A vessels exhibited serviceable bearing condition within manufacturer allowables. Representative results are presented for Vessels 1 and 3.

Vessel 1 (VTB Giang Hai, 3 years, international): Diametral clearance grew from the nominal 0.80mm to an average of 1.50mm, within the allowable limit of 5.0mm for this bore size. Bearing surface Ra averaged 2.1µm (new: 0.9-1.2 µm). Visual inspection showed shallow, uniformly distributed wear with no deep grooving. The AISI 316 shaft sleeve $Ra=0.9\ \mu m$, confirming mild tribological conditions (Figure 1).

Figure 1. Vessel No. 1 (VTB Giang Hai) after 3 years operation: bearing surface - uniform shallow wear; AISI 316 shaft sleeve - slight scratches on the surface

Vessel 3 (PTSC 05 tugboat, 5 years, Nghi Son port): Average clearance 1.25mm (design 0.60mm; limit 4.0mm). Bearing surface showed acceptable moderate wear; shaft sleeve (AISI 421) $Ra=1.2\mu m$ with no abrasive grooving (Figure 2).

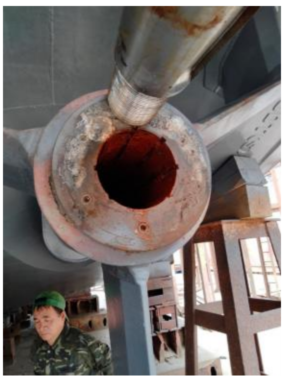

Figure 2. Vessel 3 (PTSC 05 tugboat) after 5 years, Nghi Son port: bearing bore - moderate uniform wear; AISI 421 shaft - no abrasive damage

4.2. Group B - Estuarine Vessels: Moderate to Rapid Wear

Vessel 6 (Hoang Gia tugboat, twin-shaft, 3 years): This vessel presented a representative severe wear case. The owner routinely operated on a single shaft while the second rotated freely without cooling water, causing dry-contact seizure. Measured clearance on the dry-running bearing exceeded 12mm. The AISI 316 shaft sleeve exhibited deep circumferential scoring. A net-fouling incident damaged the propeller, causing shaft imbalance and increasing radial load on the aft bearing (Figure 3).

Table 2. Dimensional results and failure modes - Groups A

Vessel	Svc (years)	Nom. CL (mm)	CL fwd	CL mid
Giang Hai	3	0.80	1.58	1.55
Dong Ho	5	1.20	2.56	2.52
PTSC 05	5	0.60	1.25	1.20
PTSC 07	3	0.60	1.52	1.48
VSICO	3	1.20	3.05	2.85

Note: CL - diametral clearance; all units in mm.

Figure 3. Vessel 6 (Hoang Gia tugboat) after 3 years: bearing bore with deep circumferential scoring from dry-running; AISI 316 sleeve with severe abrasive grooves and corrosion pits

Vessel 7 (Lucky Star rice carrier, 3 years): Cooling-water passages found partially blocked by silt accumulation, reducing coolant flow to below 40% of design value. Bearing Ra measured 4.8µm; diametral clearance 8.42mm - exceeding the 6.0mm allowable limit (Figure 4).

4.3. Group C - Inland/Dredging Vessels: Premature Failure

All three Group C vessels failed before the 5-year design interval, with bearing lives of 1.5-2 years .

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Figure 4. Vessel 7 (Lucky Star rice carrier) after 3 years: The cooling-water grooves were partially blocked by silt deposits due to silt buildup, diametral clearance 8.42 mm - exceeding the 6.0 mm allowable

Vessel 8 (Viet Thuan coal carrier, 2 years, Tra Vinh river mouth, TSS 380-520 mg/L): Pronounced longitudinal abrasive grooving on all three bearing segments - groove depth 35-70 µm, width 120-250 µm. Diametral clearance 10.68mm (limit: 6.0mm); shaft sleeve *Ra* 3.9µm (Figure 5).

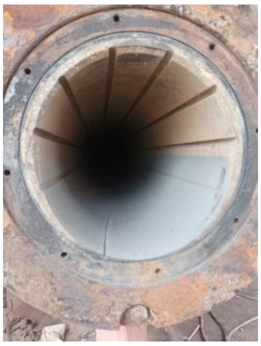

Figure 5. Vessel 8 (Viet Thuan, Tra Vinh river) after 2 years: Severe three-body abrasive grooving across all three bearing stave sections caused by sand ingress from unfiltered cooling water (TSS 380-520

Vessel 9 (Hai Duong sand dredger, 2 years): Operating directly in the dredging zone (TSS estimated 600-1200 mg/L). A net-fouling incident damaged the propeller, causing shaft imbalance. Bearing clearance 12.1 mm after 2 years; delamination failure with detached composite fragments in 3 of 4 staves; surface crack on shaft sleeve in aft bearing zone (Figure 6).

Vessel 10 (Thai Binh power-station cooling pump, 6 months): Bearing failed after only 6 months. Shaft runout measured at 0.18mm prior to installation (*allowable:≤0.05mm*). Combined with Thai Binh river water (TSS ~450mg/L), this produced asymmetric loading and highly non-uniform wear (1.6mm on loaded side vs. 0.5mm opposite). Silt deposition was found blocking 40% of the cooling-water inlet cross-section (Figure 7).

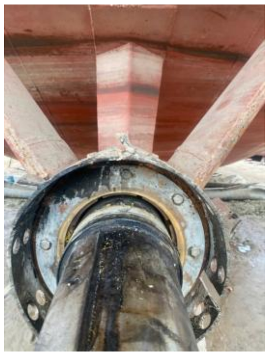

Figure 6. Vessel 9 (Hai Duong sand dredger) after 2 years: Bearing bore with delamination failure and embedded sand debris; shaft sleeve with deep longitudinal scratching and pitting

Figure 7. Vessel 10 (Thai Binh power-station pump) after 6 months: Sand and silt deposits blocking cooling-water passages and bearing housing. Shaft runout 0.18mm (3.6× allowable) combined with high TSS produced asymmetric premature failure

5. Analysis and Discussion

5.1. Dominant Failure Mechanisms

Field evidence on all ten vessels showed four main failure modes (Table 4).

Three-body abrasive groove wear was the dominant mechanism in Group C. Sand particles (SiO_2, Mohs 7) entered the bearing gap, which was 3-4 times harder than the ACM surface, creating micro-cut grooves parallel to the axis of rotation. Groove depth correlated with particle size and concentration; the 100-250 µm range caused the most damage, consistent with the K_env prediction from equation (2). This size range is characteristic of Vietnamese riverbed sand [6].

Surface spalling was observed on the bearings of the Hai Duong dredger, indicating that cyclic impact

Table 3. Dimensional results and failure modes - Groups B and Groups C

Vessel	Svc (years)	Environment	CL fwd	CL mid
Hoang Gia	3	River mouth	>3.5	>3.5
Lucky Star	3	Coastal/intl.	>6.0	>6.0
Viet Thuan	2	River mouth	>6.0	>6.0
Hai Duong	2	Dredging zone	>3.5	>3.5
Thai Binh	0.5	River	>2.5	>2.5

Note: All clearance values in mm.

Table 4. Failure mode summary by vessel group

Failure mode	Vessels affected	Primary driver
3-body abrasive grooving	5/10	Sand ingress
Surface delamination	3/10	Cyclic impact fatigue
Dry-contact seizure	1/10	No cooling water
Silt-induced flow restriction	4/10	Fine sediment
Tribocorrosion	3/10	Cl^- + mechanical wear

loads from dense sand and mud created subsurface cracks at the fabric-resin interface, eventually spalling the composite pieces. This mode occurred after the wear limit had been exceeded.

Dry contact jamming occurred on the Hoang Gia vessel due to operating a shaft without coolant - a misuse scenario that produced characteristic circumferential scratches different from longitudinal wear grooves.

Flow blockages caused by mud (Lucky Star, Thai Binh, Hai Duong) gradually clogged the bearing coolant channels and water supply lines, causing hydrodynamic lubrication film collapse and a shift from full-film lubrication to mixed/ boundary lubrication. This mechanism may occur even in the absence of coarse sand particles and requires remediation by regular flushing.

5.2. Quantitative Comparison with ACM Performance Data

ACM L2 Marine data [3] quotes 0.8-2.0 mm total clearance growth over 3 years in clean water (0.27-0.67 mm/years). Group A results (Table 2) give 0.20-0.30 mm/years, consistent with the lower end of this range. Group C vessels show 2.5-4.0 mm/years at similar shaft sizes - a 10-12× increase directly attributable to sand abrasion. Applying Eq. (3) with Group C parameters *(D=160mm, B=640mm, v=2.1m/s, TSS=500mg/L,* d_{50}*=175µm)* gives predicted life 1.8-2.3 years, in close agreement with the observed 2-years failure interval (*error<15%).*

The ACM material's known advantage in shaft sleeve compatibility is confirmed by Group A results: No significant sleeve damage was observed. By contrast, Group C sleeves showed Ra increases from 0.4-0.6 µm to 1.9-4.2 µm, demonstrating that without filtration, even high-quality composite bearings cannot prevent shaft degradation.

5.3. Installation Quality and Shaft Alignment

The Thai Binh pump case demonstrates that installation defects are independent root causes. Shaft runout of 0.18 mm (3.6× allowable) introduced an alternating bending moment producing the characteristic asymmetric wear observed. This finding is particularly relevant to the Vietnamese inland vessel fleet, where shaft machining is often contracted to small workshops without rigorous dimensional verification. Runout measurement and correction must be treated as mandatory - not optional - pre-installation steps.

6. Recommendations

Five engineering recommendations are proposed to extend bearing and shaft service life in sand/sediment environments:

R1 - Dual-stage cooling-water filtration

Fit a self-cleaning two-stage strainer on the bearing cooling-water supply: Stage 1 (200µm) removes coarse debris; Stage 2 (50µm) removes the most damaging fine-medium sand fraction. This reduces particle ingress by 80-90% and is estimated to extend bearing life by 2.5-3.5×. Installation cost ~VND 15-25 million/vessel is recovered within one avoided unscheduled drydock**.**

R2 - Environment-specific maintenance intervals

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R3 - Pre-installation shaft verification

Mandatory shaft journal runout measurement (*allowable* $\le 0.05mm$) and bearing housing alignment check prior to bearing installation. Any runout exceeding tolerance must be corrected by journal re-grinding. Verify cooling-water passage cross-sections for freedom from silt deposition.

R4 - Use of high wear-resistant bearing materials

Use propeller shaft bearings made of materials with high wear resistance and high elasticity to reduce the rate of wear from sand and sediment in the coolant (such as rubber bearings and Feroform materials,…)

R5 - Twin-shaft cooling-water discipline

On multi-shaft vessels, each idle shaft must be either: (a) positively locked against rotation by a shaft brake, or (b) continuously supplied with cooling water ($\geq 6L/min$). Operating a free-rotating shaft without lubrication significantly increases the risk of bearing failure within months regardless of bearing material quality.

7. Conclusion

This paper presents the first systematic drydock survey of ACM L2 Marine composite bearing performance across a range of Vietnamese vessel operating environments. The principal findings are:

(1) In clean offshore conditions, ACM bearings achieve 0.13-0.16 mm/years diametral clearance growth, within manufacturer specification.

(2) Sand and sediment contamination in dredging environments was observed to accelerate wear by approximately 3.8-6.3 times within the surveyed fleet, reducing service life to 1.5-2 years.

(3) The dominant failure mode is three-body abrasive grooving; secondary modes are delamination, silt-flow restriction, dry-contact seizure, and tribocorrosion.

(4) The extended Archard wear model (Eq. 3) predicts field service lives with mean *error<15%*, validating its use for maintenance planning.

(5) Shaft installation defects (eccentricity, misalignment) are independent root causes that exacerbate wear caused by debris.

Five recommendations focusing on filtration, condition-based maintenance, shaft preparation, using materials with high wear resistance, and operating discipline provide a cost-effective roadmap to extend bearing life toward a 5-year design target in demanding dredging applications.

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REFERENCES

[1] Litwin, W. (2011), *Water-lubricated marine bearings - experimental research*, Proc. Inst. Mech. Eng. Part J, Vol.225(5), pp.436-444.

[2] Orndorff, R. L. (1985), *Water-lubricated rubber bearings, history and new developments*, Naval Engineers Journal, Vol.97(6), pp.39-52.

[3] ACM Bearings Ltd. (2023), *ACM L2 Marine composite bearing - Technical data sheet*.

[4] Huang, Q., Liu, X., Li, J., & Zhang, Y. (2020), *Effect of sand contamination on wear of water-lubricated polymer bearings*, Wear, pp.448-449, 203201.

[5] Rao, Z., Wang, S., & Ruan, S. (2012), *Wear behaviors of bearings under sand-contaminated water*, Tribology Transactions, Vol.55(4), pp.429-437.

[6] Ministry of Natural Resources and Environment of Vietnam (2022), *National Environmental Status Report 2022*, Hanoi: MONRE.

[7] Litwin, W. (2014), *Influence of local bush wear on water-lubricated bearing load capacity*, Tribology International, Vol.72, pp.123-134.

[8] Dong, C., Yuan, C., Bai, X., Yan, X., & Qin, Z. (2015), *Wear of textured shaft/rubber bearing pair*, Tribology International, Vol.90, pp.512-520.

[9] Yuan, C., Guo, Z., Tao, W., Dong, C., & Bai, X. (2016), *Mixed lubrication of stern tube bearings*, Tribology International, Vol.101, pp.67-75.

[10] Jia, C., Peng, X., & Meng, X. (2021), *Tribological properties of rubber bearings under heavy load*, Tribology International, 157, p.106891.

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