Bearing design in a bitumen mixer machine

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Abstract
The bitumen mixer machine operates under high dynamic loads and intensive rotation, making the bearing system design a crucial aspect in ensuring the reliability and smooth operation of the machine. This final project aims to analyze the axial and radial loads on the bearings, determine the appropriate type and bearing specification, and calculate the bearing service life using free body diagram method, dynamic equivalent load calculation, and basic dynamic load approach. The calculation results show that bearing D receives a radial load of 487.52 N and an axial load of 228 N with a basic dynamic load of 10.514.14 N, while bearing E receives a radial load of 222.28 N and an axial load of 228 N with a basic dynamic load of 8.371.82 N. The selected bearings are single deep groove ball bearing type 6207 2RS for point D with a dynamic load capacity of 27.000 N and type 6205 for point E with a dynamic load capacity of 14.800 N, both declared safe and meeting service requirements with a bearing service life of 4.2 years at a 95% reliability factor.

1. Introduction

Asphalt, or bitumen, is the primary material used as a binder in road pavement construction. This substance is dark in color and highly viscous at room temperature. Chemically, bitumen belongs to a group of complex hydrocarbon compounds that also contain small amounts of elements such as sulfur, nitrogen, and oxygen [1]. It is characterized by its viscoelastic properties, meaning that asphalt melts when heated to a certain temperature and hardens again when the temperature drops [2].

As the primary material for transportation infrastructure, asphalt's performance depends not only on the quality of raw materials but also on technological innovations and environmentally friendly approaches in the production process. Environmental pollution caused by plastic waste has become a serious concern in many countries, including Indonesia, because high plastic production is not matched by adequate waste management systems, resulting in most plastic waste ending up in the ocean or in open landfills. In fact, Indonesia is now the world's second-largest contributor of plastic waste after China, with an annual volume of 8.96 million metric tons [3]. This situation has spurred efforts in materials engineering to utilize plastic waste as an environmentally friendly additive in road construction one such approach involves adding plastic to asphalt to enhance performance while simultaneously reducing the volume of waste polluting the environment [4].

The addition of plastic waste to asphalt mixtures is an effective method for improving the quality of road pavements, which can extend their service life and enhance their resistance to water, moisture, and repeated traffic loads [5]. Other studies also confirm that asphalt mixtures modified with plastic waste can improve stability and plastic fatigue resistance [6], while also providing environmental benefits by transforming waste into useful construction materials [7].

To ensure that the mixture of bitumen and plastic blends perfectly, the mixing process must be carried out at a specific temperature and stirring speed. If this process is unstable, the plastic will not melt evenly, resulting in a non-homogeneous mixture, which ultimately reduces the performance of the asphalt in the field [8]. Therefore, a bitumen mixer capable of continuously maintaining stable temperature and agitator rotation throughout the process is required. This mixer is designed to blend highly viscous materials until they reach a homogeneous state, thereby producing a mixture with optimal adhesion and durability.

In the operating system of a mixing machine, there are several mechanical components that play important roles, including the drive motor, transmission, mixing shaft, frame, and bearings. Bearings are one of the key components that determine the smoothness of rotation and the stability of the mechanical system. These components support the shaft so that it can rotate without excessive friction and can withstand both radial and axial loads during the mixing process.

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Mixing machines often face technical problems in the form of premature wear on mechanical components such as bearings, caused by inadequate lubrication, excessive workloads, and uneven pressure distribution during machine operation [9]. These conditions directly impact the quality of the asphalt-plastic mixture and reduce production efficiency. Therefore, the proper design of the bearing system is a critical factor in ensuring the reliability and operational lifespan of bitumen mixers used in the process of mixing bitumen with plastic waste. Thus, the writing of this thesis serves as a first step toward improving the efficiency and reliability of bitumen mixers, as well as contributing to the development of sustainable and environmentally friendly asphalt-plastic mixing technology.

2. Method

2.1. Design Stages

The design process for bolted and welded joints in a bitumen mixer consists of several stages, as shown in Figure 1.

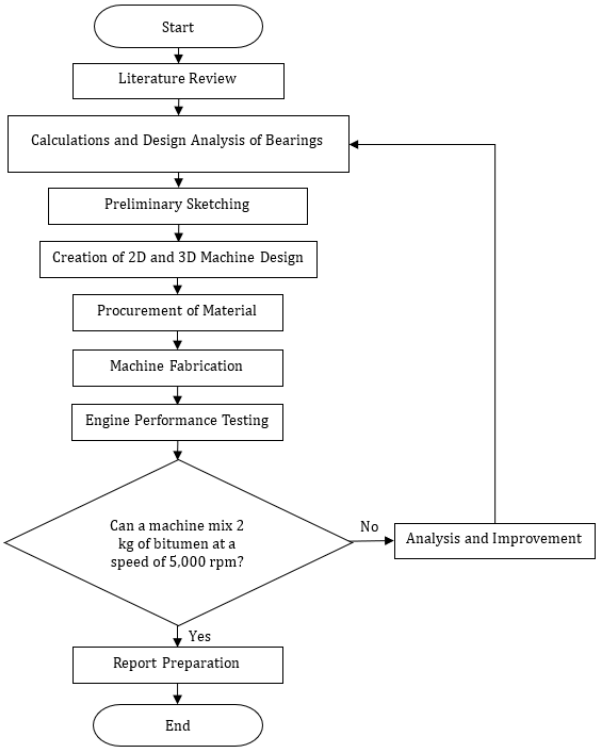


Figure 1. Flow Diagram Design Process

2.2. Literature Review

A literature review is the first step in gathering data or information to serve as a theoretical foundation for asphalt mixing plants, drawn from journals and articles related to the design of asphalt mixing plants. This information may include the specifications of the components used, the electrical system, advantages and disadvantages, and so on.

2.3. Calculate and Design Analysis of Bearings

A bearing is a mechanical component that serves as a support for a shaft, allowing it to rotate with minimal friction. The service life of a bearing is influenced by the load, rotational speed, lubrication conditions, and operating temperature during use. Therefore, calculating the service life of a bearing is important to ensure reliability and prevent system failure [10].

2.4. Preliminary Sketching

The sketching process is carried out based on the data and information gathered during the project's initiation phase. The results of this sketching process will serve as a reference for creating the 3D design of the bitumen mixer. A preliminary sketch of the bitumen mixer can be seen in Figure 2.

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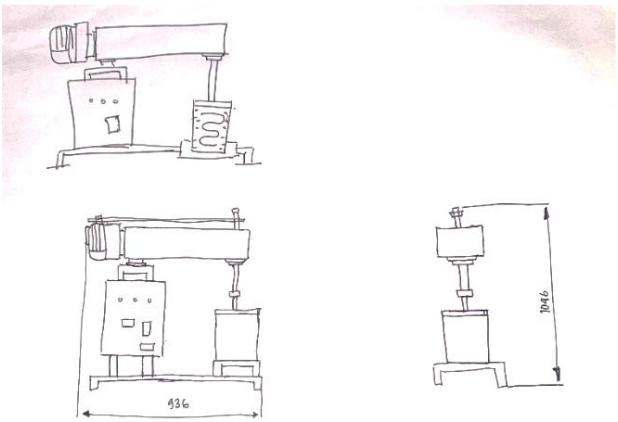


Figure 2. Preliminary Sketch of a Bitumen Mixer Machine

2.5. Creation of 2D and 3D Machine Designs

The next step, after the engine design has undergone a series of evaluations and approved modifications, is to create a 3D model of the engine using SolidWorks software, followed by the creation of 2D drawings by converting the 3D model into 2D drawings to facilitate the production process. The 2D and 3D designs of the bitumen mixer can be seen in Figure 3 and Figure 4.

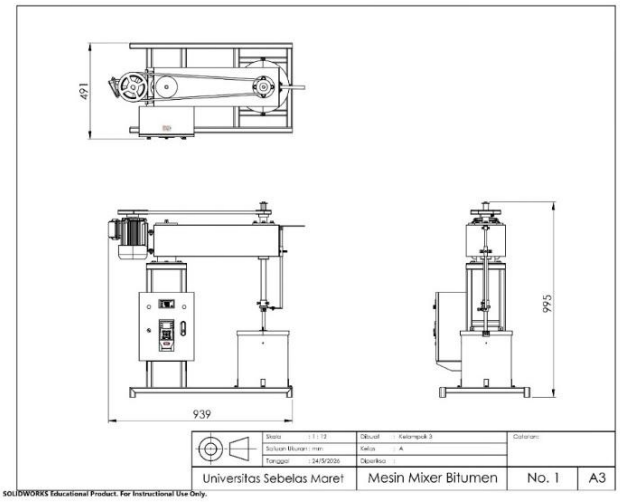


Figure 3. 2D Design of a Bitumen Mixer Machine

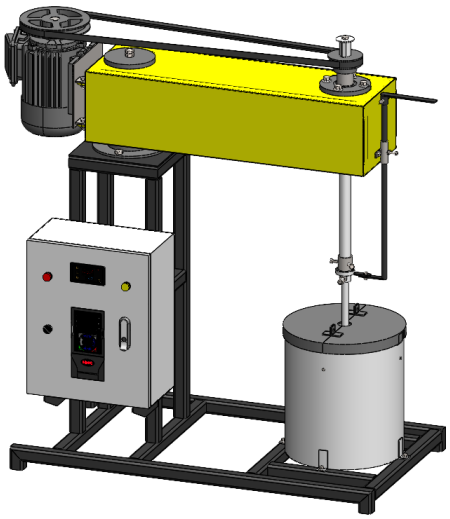


Figure 4. 3D Design of a Bitumen Mixer Machine

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2.6. Procurement of Materials

Procurement is a systematic process carried out to fulfill the goods or services required in a work plan [11]. In the process of procuring materials for this bitumen mixer, a bill of materials was created to support a structured and systematic procurement process. A bill of materials is a document containing information regarding a product's composition, including material specifications, material dimensions, and the quantities required in the production process of a product [12]. In addition to the bill of materials, a cost budget plan must also be prepared during the material procurement process to serve as a reference for estimating the total costs required for both material procurement and the overall production process [13].

2.7. Machine Fabrication

The machine assembly process begins after all preparatory work such as sketch drawings, technical drawings, and material preparation has been completed. This process must be carried out carefully and safely to prevent errors during production and avoid workplace accidents: Procurement of materials; Cutting of materials; Machine fabrication; Finishing.

2.8. Engine Performance Testing

Engine performance testing is conducted to determine whether the engine's performance is optimal and meets targets.

a. No-Load Testing. No-load testing is performed by starting the engine in an idle state (without load) to assess the engine's initial performance and the stability of its basic mechanical components, such as the engine, transmission system, bearings, and crankshaft.

b. Testing with a bitumen load without reinforcing material. Machine testing with a load of pure bitumen without reinforcing material is conducted by starting the machine with the mixing drum filled with pure bitumen. This test serves to determine the machine's ability to mix hot liquid bitumen. This process also evaluates the performance of the machine's heating system.

c. Testing process with a bitumen load containing reinforcing material. The machine testing process using a load of bitumen mixed with reinforcing material specifically plastic that has been processed into powder form is conducted by first adding pure liquid bitumen to the mixing drum, then adding the plastic powder mixture last, and finally starting the machine. This test simulates the machine's performance when it is later used with material that has been mixed with reinforcing agents.

2.9. Analysis and Improvement

After the testing process is completed, a performance analysis of the machine is conducted. If the machine's performance is deemed suboptimal or does not meet the target, the process continues with improvements to optimize the machine's condition and performance.

2.10. Report Preparation

All stages from design and assembly to machine testing are documented in a scientific report that includes the background, literature review, design methodology, results and their discussion, and a conclusion with recommendations. The report is prepared in accordance with scientific writing standards and is supplemented with reliable references and figures to support the technical data. This report is also designed to serve as a guide or reference for the development of similar research in the future. The writing process was carried out in stages, involving several rounds of guidance and revisions to ensure that the content complies with applicable academic standards.

3. Results and Discussion

3.1. Torque Calculation

Calculations were performed to determine the required torque value. The torque calculation for the bitumen mixer is intended to determine the magnitude of the rotational force acting on the shaft. In the design of this bitumen mixer, a 1 HP electric motor is used as the main drive, with a rotational speed of 2900 rpm. Based on the power and rotational speed of the electric motor. Torque can be found using the following equation on Table 1.

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Table 1. Torque on the Shaft

Parameters	Equation	Data	Results
Torque (T)	$T = \frac{P.60}{2.\pi.N}$	P = 746 Watt N = 2900 rpm	2.85 Nm

Based on the torque calculations in Table 1, the above calculation yields a shaft torque of 2.85 Nm.

3.2. Structural Statics on the Shaft

Structural statics is used to determine the magnitude of the load borne by the bearings on the shaft as supports. This analysis is performed by modeling the shaft as a horizontal beam that receives loads from components mounted along its length, and then determining the reactions at the support points. Using the free-body diagram approach, all forces acting on the shaft whether external forces (loads) or reaction forces at the support can be systematically broken down into horizontal and vertical components. These results are then used as the basis for calculating the reaction forces at each point. Figure 5 shows a structural statics diagram of the shaft, and Figure 6 shows the free-body diagram for the shaft.

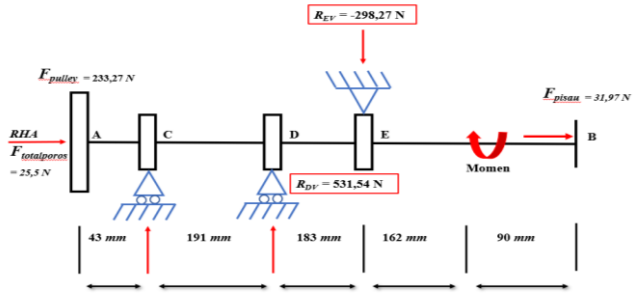


Figure 5. Structural Statics of Shafts



Figure 6. Free Body Diagram

The structural statics and free-body diagrams in Figure 5 and Figure 6 are used to determine the magnitude of the load borne by the bearing on the shaft. Before determining the load borne by the bearing, first determine the forces on the shaft and pulley, which can be calculated by referring to Table 2.

Table 2. Forces on the Pulley and Forces on the Blade

Parameters	Equation	Data	Results
F_{pulley} (F1)	$F_{pulley} = (T_1 + T_2) + W_{pulley}$	T_1 = 195.1 N T_2 = 13.61 N W_{pulley} = 24,525 N	233.27 N
F_{blade} (F3)	F_{blade} = (W_{knife} x Number of Blade) + $W_{bitumen}$	W_{knife} = 5.54 N Number of Knife = 4 $W_{bitumen}$ = 9.81 N	a.97

Once the force is known, determine the load on the bearing using the equation in Table 3.

Table 3. Determining the Load on the Bearing

Parameters	Equation	Data	Results
Determine the load at point E (REV)	$\sum M_D = 0$ $-(F_{pulley} .234) - (R_{EV}.183) = 0$	F_{pulley} = 233.27 N	-298.27 N
Determine the load at point C (RCV)	$\sum M_D = 0$ $F_{pulley}(x_A - x_D) + R_{CV}(x_C - x_D) + R_{EV}(x_E - x_D) = 0$	F_{pulley} = 233.27 N R_{EV} = -298.27 N	0.01 N
Determine the load at point D (RDV)	$\sum F_y = 0$ $F_{pulley} + R_{CV} + R_{DV} + R_{EV} = 0$	F_{pulley} = 233.27 N R_{CV} = 0.01 N R_{EV} = -298.27 N	531.53 N

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Parameters	Equation	Data	Results
Determine the axial force on shaft	$T = F_A$ x r	T = 2850 Nm r = 12.5 mm	228 N
Determine the load at point E (REH)	$\sum Fx = 0$ $R_{HA} - F_A - F_{blade} - R_{EH} = 0$	R_{HA} = 25.5 N F_A = 228 N F_{blade} = 31.97 N	-234.47 N

After performing the calculations, the forces acting on the shaft have been identified, allowing the bearing to be designed.

3.3. Bearing Design

In designing a bitumen mixer with a blade shaft rotational speed of 5.000 rpm, the bearings are expected to support the load and withstand the forces acting on the machine's blade shaft. Bearing calculations are used to determine the machine's design so that it remains within the required limits for several parameters, as shown in Table 4.

Table 4. Bearing Design

Parameters	Equation	Data	Results
Dynamic Equivalent Load (W)	$W = (X.V.W_R + Y.W_A)$	X = 1 V = 1 W_R = 531.53 N Y = 0 W_A = 0	531.53 N
Rating Life (L)	$L = 60.N.L_H$	N = 2500 rpm L_H = 20.000	$3000.10^6 rev$
Dynamic Load (C)	$C = W\left(\frac{L}{10^6}\right)^{1/k}$	W = 531.53 N L = $3000.10^6 rev$ K = 3	7664.86 N

From the calculations above, the dynamic load rating of the bearing is found to be 7664.86 N. Therefore, the specifications of the bearing used are required for comparison. The specifications for the 6207 2RS bearing can be found in Table 5.

Table 5. Spesifikasi *Bearing* 6207 2RS [14]

Spesifikasi 6207 2RS	
Dynamic Load Capacity (C)	27000 N
Static Load Capacity (C_0)	15300 N
Bore Diameter(d)	35 mm
Outer Diameter(D)	72 mm
Flange Width (B)	17 mm

Based on Table 5, the acceptable dynamic load capacity of the 6207 2 RS bearing is greater than the dynamic load on the bitumen mixer's bearing; therefore, the bearing design is SAFE and meets the service life requirement of L_H = 20.000 hours. Next, the bearing life calculation is presented Table 6 below.

Table 6. Condition of Bearing Age

Parameters	Equation	Data	Results
Bearing Reliable (L_n)	$L_n = a_1.a_2.a_3.L_H$	a_1 = 0.62 (95%) a_2 = 1 a_3 = 1 L_H = 20.000	12.400 Hours
Bearing Life (L_b)	$L_b = \frac{L_n}{l.365\ hari}$	L_n = 12.400 Hours l = 8 Hours	4.2 Years

Based on the calculations for the bearing replacement interval in Table 6 using a reliability factor of 95%, an operating time of 8 hours per day, and 365 days per year the bearing life is 4.2 years, or 4 years, 2 months, and 12 days. For the second bearing, the calculation can be performed using the following equation Table 7.

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Table 7. Bearing Design

Parameters	Equation	Data	Results
Dynamic Equivalent Load (W)	$W = (X.V.W_R + Y.W_A)$	X = 0.56 V = 1 W_R = 298.27 N Y = 1.8 W_A = 234.47 N	589.07 N
Rating Life (L)	$L = 60.N.L_H$	N = 2500 rpm L_H = 20.000	$3000.10^6 rev$
Dynamic Load (C)	$C = W\left(\frac{L}{10^6}\right)^{1/k}$	W = 589.07 N $L = 3000.10^6 rev$ K = 3	8495 N

From the calculations above, the dynamic load rating of the bearing is found to be 8495 N. Therefore, the specifications of the bearing used are required for comparison. The specifications for the 6205 bearing can be found in Table 8.

Table 8. Spesifikasi *Bearing* 6205 [15]

Specification 6205	
Dynamic Load Capacity (C)	14800 N
Static Load Capacity (C_0)	7800 N
Bore Diameter(d)	25 mm
Outer Diameter(D)	52 mm
Flange Width (B)	15 mm

Based on Table 8, the acceptable dynamic load capacity of the 6205 bearing is greater than the dynamic load on the bitumen mixer's bearing; therefore, the bearing design is SAFE and meets the service life requirement of L_H = 20.000 hours. Next, the bearing life calculation is presented Table 9 below.

Table 9. Condition of Bearing Age

Parameters	Equation	Data	Results
Bearing Reliable (L_n)	$L_n = a_1.a_2.a_3.L_H$	a_1 = 0.62 (95%) a_2 = 1 a_3 = 1 L_H = 20.000	12.400 *Hours*
Bearing Life (L_b)	$L_b = \frac{L_n}{l.365\ hari}$	L_n = 12.400 *Hours* l = 8 *Hours*	4.2 *Years*

Based on the calculations for the bearing replacement interval in Table 9 using a reliability factor of 95%, an operating time of 8 hours per day, and 365 days per year the bearing life is 4.2 years, or 4 years, 2 months, and 12 days.

3.4. Results

The purpose of this machine testing process is to measure the performance of the previously assembled bitumen mixer. This testing process is conducted in two stages. The first stage involves bitumen without any reinforcing material added, and the second stage involves bitumen mixed with a plastic reinforcing material (type 64). This machine testing process measures the performance of each machine component, particularly the transmission system components namely, the belt and pulleys to determine whether they can effectively and safely transmit rotational power from the drive motor to the mixing shaft.

3.4.1. Testing of Bitumen Without Reinforcing Agents

This test is conducted to ensure that the transmission system components can safely transfer rotational force from the electric motor to the mixing shaft without excessive vibration. In this test phase, liquid bitumen without reinforcing agents, heated to a temperature of 160°C, is used. This test also serves to measure the performance of the inverter and thermostat in the temperature and mixing speed control system. A diagram of the machine test can be seen in Figure 7.

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Figure 7. Machine Testing Process

Test results show that every component of the bitumen mixer, such as the belt drive system and pulleys, is capable of transmitting rotational force from the electric motor to the mixing shaft safely and without excessive vibration. The rotational speed of the drive system is also constant and unimpeded. Control elements such as the inverter also function properly in regulating the mixing speed. The thermostat also functions effectively as a temperature control element, maintaining a stable temperature throughout the mixing process. A view of the machine in operation is shown in Figure 8.



Figure 8. A bitumen Mixer Machine in Operation

3.4.2. Testing of Bitumen with Reinforcing Materials

This test is conducted to ensure that the mixing process is carried out properly so that it produces a uniform mixture of bitumen and reinforcing materials. In this stage of the test, liquid bitumen and reinforcing materials in the form of plastic powder are used, as shown in the Figure 9.



Figure 9. Testing Process for a Bitumen Mixer Using a Mixture of Reinforcing Materials

The test results show that the final mixture of bitumen and reinforcing material can be blended evenly without any lumps or air bubbles. This indicates that the rotational speed of the mixing shaft remained constant and stable throughout the mixing process, and that temperature control was effective, ensuring that the

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temperature remained stable and did not drop during the mixing process. Images of the reinforcing material mixture and the final result of the mixing process can be seen in Figure 10 and Figure 11.



Figure 10. Final Result of the Mixing Process

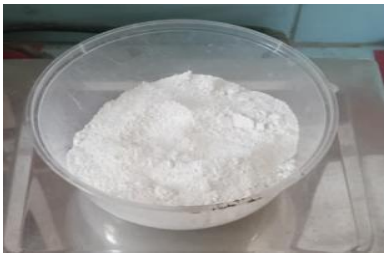


Figure 11. A Mixture of Reinforcing Materials in Bitumen

4. Conclusion

Based on the results of the design and testing of the bitumen mixer, the following conclusions can be drawn:

a. Based on the calculations, the dynamic load on bearing D is 7664.86 N, whilst the acceptable dynamic load for a type 6207 bearing is 27000 N. The dynamic load on bearing E is 8495 N, whilst the acceptable dynamic load for a type 6205 bearing is 14800 N.

b. The bearing used in the bitumen mixer, operating at 5.000 rpm on the mixing shaft, is a single deep-groove ball bearing, as this type of bearing can withstand both axial and radial loads. The 6207 2RS bearing has a bore diameter of 35 mm, an outside diameter of 72 mm, a width of 17 mm, and a service life under normal operating conditions of 4.2 years, or 4 years, 2 months and 12 days. Meanwhile, the 6205 bearing has a bore diameter of 25 mm, an outside diameter of 52 mm, a width of 15 mm, and a service life under normal operating conditions of 4.2 years, or 4 years, 2 months and 12 days.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

Data Availability

The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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