# EFFECT OF SPRAY FORMING ON MICROSTRUCTURE AND TRIBOLOGICAL PERFORMANCE OF AL30Pb BEARING ALLOY

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## Abstract

Al–Pb bearing alloys have attracted considerable attention for automotive and aerospace applications owing to their low coefficient of friction, excellent thermal conductivity, and superior seizure resistance. However, the processing of AlPb alloys through conventional casting techniques is challenging because of liquid immiscibility and the large density difference between aluminium and lead, resulting in severe macrosegregation and coarse microstructures. In the present study, spray forming was employed as an alternative rapid solidification technique to fabricate Al–30Pb bearing alloy with improved microstructural characteristics and tribological performance. The alloy was atomized using nitrogen gas at a pressure of 4.0 MPa and deposited onto a copper substrate to obtain dense spray-formed preforms. Optical microscopy was used to examine the microstructure, while dry sliding wear tests were conducted using a pin-on-disc tribometer under loads ranging from 10 to 50 N and sliding velocities between 1 and 3 m/s. The spray-formed alloy exhibited a refined equiaxed α-Al matrix with uniformly distributed fine Pb particles, in contrast to the coarse needle-like Pb morphology observed in the conventionally cast alloy. The refined microstructure significantly reduced wear rate and coefficient of friction under all test conditions. Examination of worn surfaces further confirmed reduced adhesive wear, shallow grooves, and limited surface damage in the spray-formed alloy compared with the severe delamination and deep scoring marks observed in the cast alloy. The improvement in tribological behaviour is attributed to rapid solidification, microstructural refinement, and homogeneous distribution of lubricating Pb particles. The study demonstrates that spray forming is an effective processing route for producing high-performance AlPb bearing alloys with enhanced wear resistance and frictional characteristics.

**Keywords:** Spray forming; Al30Pb alloy; Bearing alloy; Rapid solidification; Wear behaviour; Tribology; Coefficient of friction.

## 1. Research Background

AlPb bearing alloys are widely used in automotive and aerospace applications because of their excellent thermal conductivity, low density, and self-lubricating properties. However, conventional casting of Al–Pb alloys is hindered by liquid immiscibility and density differences between aluminium and lead, resulting in macrosegregation and non-uniform microstructures that degrade tribological performance. Spray forming has emerged as an effective rapid solidification technique that suppresses phase segregation, refines the α-Al grain structure, and uniformly disperses Pb particles within the matrix. These microstructural improvements significantly enhance wear resistance and reduce the coefficient of friction, making spray forming a promising manufacturing route for high-performance Al–Pb bearing alloys.

## Literature Review

Recent studies (2019–2026) have reported that spray forming significantly improves the microstructure and tribological properties of Al–Pb alloys by producing fine equiaxed grains, reducing porosity, and ensuring uniform Pb particle distribution. Researchers have demonstrated that these microstructural refinements lead to lower wear rates and coefficients of friction compared with conventionally cast alloys. Although considerable work has been carried out on spray-formed aluminium alloys, studies focusing on the wear behaviour of spray-formed Al30Pb bearing alloys under varying loading conditions remain limited. Therefore, the present study investigates the effect of spray forming on the microstructure and tribological performance of Al30Pb alloy and compares its behaviour with that of conventionally cast alloy.

## 2. Materials and Methods

### 2.1 Materials

Commercial purity aluminium and lead were used as the base materials to prepare the Al–30Pb bearing alloy. The nominal composition of the alloy was 30 wt.% Pb with the balance aluminium, while copper and iron were present only as trace impurities. The alloy was initially produced by conventional casting and subsequently remelted for spray-forming experiments. The chemical composition of the alloy is presented in Table 1.

**Table 1. Chemical composition of Al–30Pb alloy (wt.%).**

| Alloy | Pb | Cu | Fe | Al |
|---|---|---|---|---|
| Al–30Pb | 30.0 | 0.002 | 0.0005 | Balance |

### 2.2 Spray Forming Process

The Al–30Pb alloy was fabricated using a spray-forming process consisting of a resistance melting furnace, an annular gas atomizer, an atomization chamber, and a copper deposition substrate. The alloy melt was heated to **750 °C** and atomized using **nitrogen gas at a pressure of 4.0 MPa**. The atomized droplets underwent rapid solidification during flight and were deposited on a copper substrate positioned **0.45 m** below the atomizer to produce a dense spray-formed preform. Rapid cooling during deposition suppressed Pb segregation and promoted a fine equiaxed microstructure with uniformly distributed Pb particles.

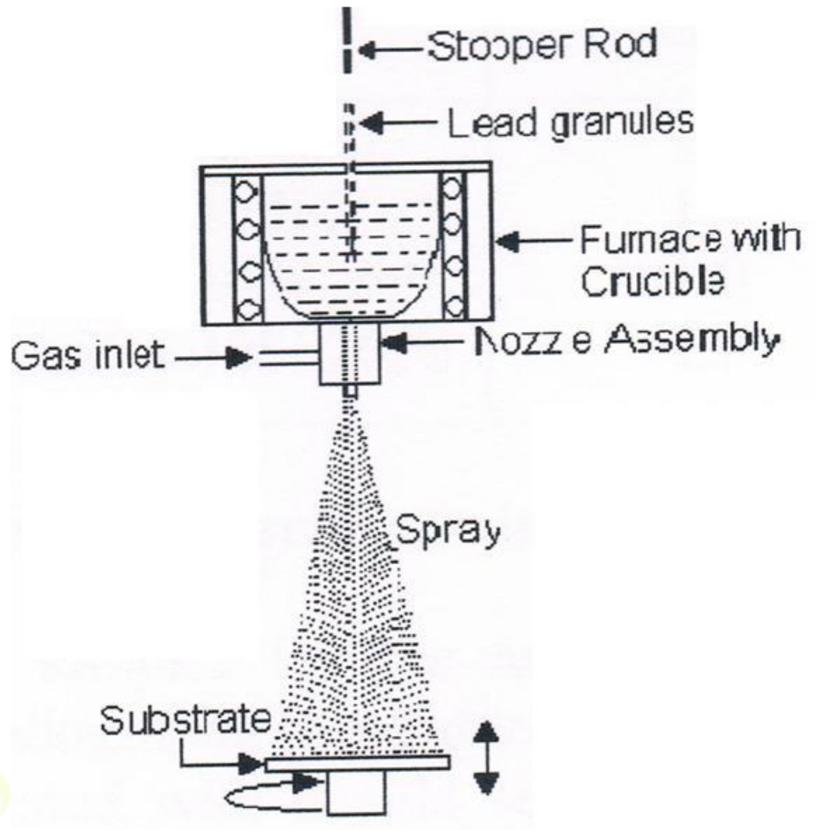


Figure 1. Schematic illustration of the spray-forming process

## 2.3 Experimental Parameters

The spray-forming parameters employed in the present investigation are summarized in Table 2.

**Table 2. Spray-forming process parameters.**

| Parameter | Value |
|---|---|
| Atomizing gas | Nitrogen ($N_2$) |
| Gas pressure | 4.0 MPa |
| Melt temperature | 750 °C |
| Gas-to-melt flow ratio | 0.89 |
| Deposition distance | 0.45 m |

## 2.4 Microstructural Characterization

Samples from both conventionally cast and spray-formed alloys were sectioned, mounted, ground using silicon carbide papers of increasing grit sizes, polished with alumina paste, and prepared using standard metallographic procedures. The polished specimens were examined using an optical microscope to evaluate grain morphology and Pb particle distribution. The spray-formed alloy exhibited a refined equiaxed α-Al matrix with uniformly dispersed fine Pb particles compared with the coarse needle-like morphology observed in the as-cast alloy.

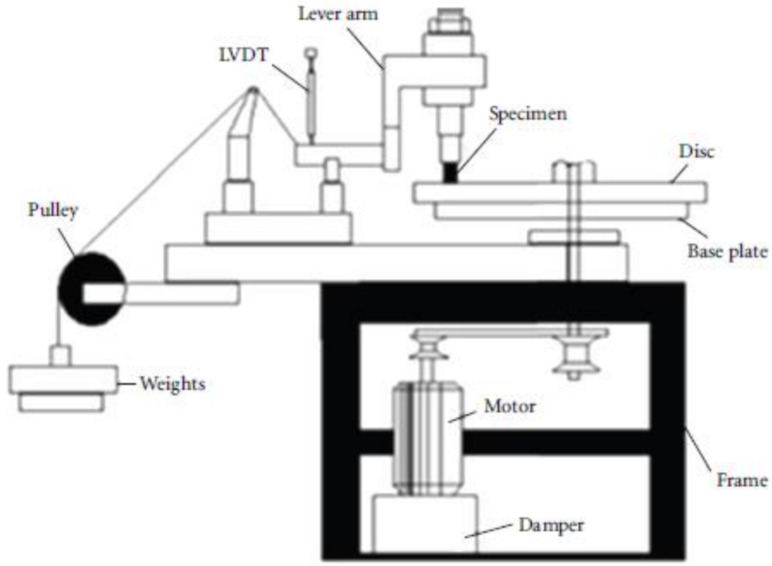


Figure 2. Pin-on-disc wear testing setup

## 3. Results and Discussion

### 3.1 Microstructural Analysis

The optical micrographs of the conventionally cast and spray-formed Al30Pb alloys are shown in Figure. 3(a) and 3(b), respectively. The as-cast alloy exhibited coarse dendritic α-Al grains with needle- and plate-like Pb phases distributed irregularly along the grain boundaries due to slow solidification and liquid immiscibility. Such a heterogeneous microstructure promotes stress concentration and adversely affects the tribological performance of the alloy. In contrast, the spray-formed alloy displayed a refined equiaxed α-Al matrix with uniformly dispersed fine globular Pb particles, predominantly smaller than 2 μm. The rapid solidification associated with spray forming suppressed Pb segregation and resulted in a homogeneous microstructure, which is beneficial for improving wear resistance and reducing friction.

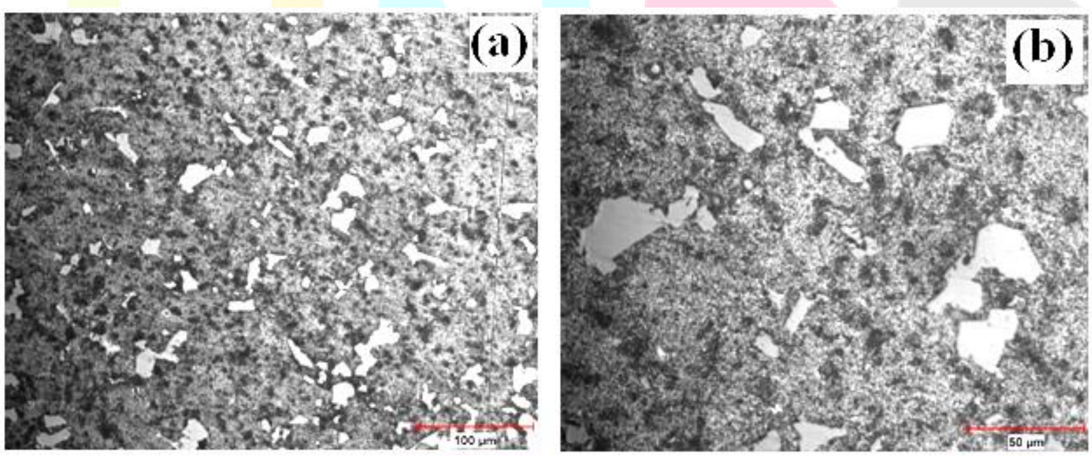


Figure 3. Optical microstructure of spray deposited Al-30Pb alloy

## 3.2 Effect of Applied Load on Wear Rate

Figure 4 illustrates the variation of wear rate with applied load for both alloys at different sliding velocities. The wear rate increased with increasing normal load for both the conventionally cast and spray-formed alloys because higher loads increased the real area of contact and promoted plastic deformation. However, the spray-formed alloy consistently exhibited a lower wear rate than the as-cast alloy under identical testing conditions. This improvement is attributed to the refined microstructure and homogeneous distribution of fine Pb particles, which act as solid lubricants and minimize direct metal-to-metal contact. The improvement became more pronounced at higher loads, indicating that the spray-formed alloy possesses superior load-bearing capability and wear resistance.

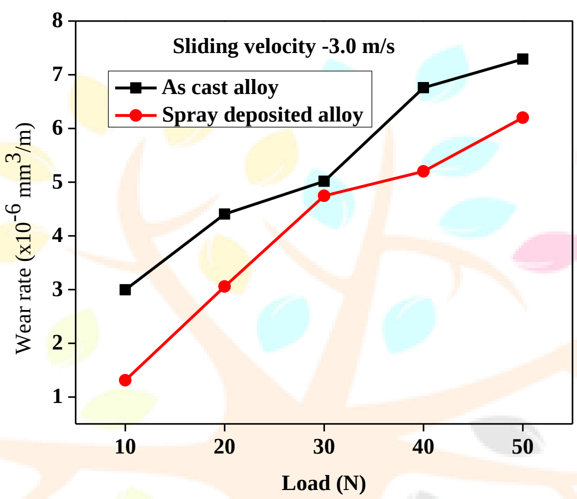


Figure 4. Variation of wear rate with load at constant speed of 3.0 m/s

## 3.3 Effect of Sliding Velocity on Wear Behaviour

An increase in sliding velocity generally resulted in higher wear rates for both alloys because of increased frictional heating and surface oxidation. Nevertheless, the spray-formed alloy maintained better wear resistance than the conventionally cast alloy throughout the investigated velocity range (1–3 m/s). The refined α-Al grains and uniformly dispersed Pb particles promoted the formation of a stable lubricating tribofilm, thereby reducing material removal even under severe sliding conditions. These results demonstrate that spray forming effectively enhances the tribological stability of Al–30Pb bearing alloys over a wide range of operating conditions.

## 3.4 Coefficient of Friction

The variation of the coefficient of friction (COF) with applied load is presented in Figure. 5. For both alloys, the COF decreased gradually with increasing load due to the formation of a mechanically mixed lubricating layer at the sliding interface. The spray-formed alloy exhibited consistently lower COF values than the conventionally cast alloy across the entire load range. The fine and uniformly distributed Pb particles released during sliding formed a continuous lubricating film that reduced adhesion between the contacting surfaces and minimized frictional resistance. Consequently, spray forming significantly improved the frictional characteristics of the Al–30Pb alloy.

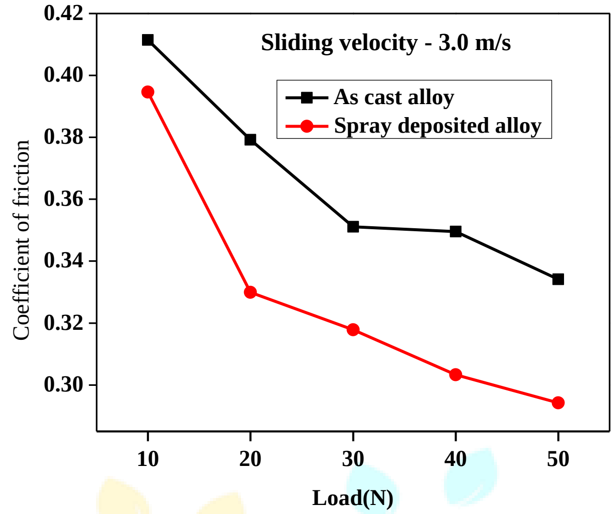


Figure 5. Variation of coefficient of friction with load at constant speed of 3.0m/s

### 3.5 Worn Surface Morphology

Representative worn surfaces after testing at a load of 50 N and a sliding velocity of 3 m/s are shown in Figure. 6. The conventionally cast alloy exhibited deep grooves, severe delamination, adhesive patches, and extensive plastic deformation, indicating dominant adhesive and abrasive wear mechanisms. In contrast, the spray-formed alloy showed comparatively smooth wear tracks with shallow grooves and limited surface damage. The reduction in surface deterioration is attributed to the refined microstructure and the formation of a protective Pb-rich lubricating layer during sliding. These observations confirm that spray forming effectively suppresses severe wear mechanisms and improves the tribological performance of Al–30Pb bearing alloys.

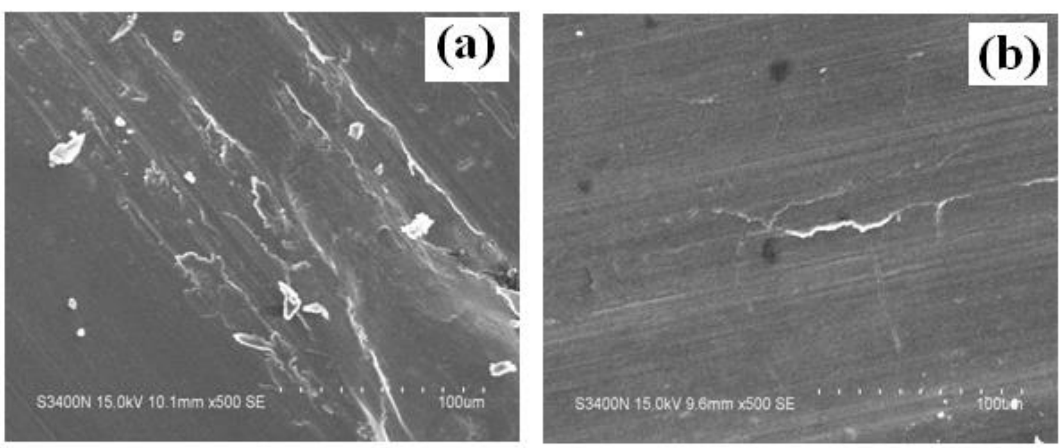


Figure 6. Worn surfaces of Al-30 Pb alloys (a) as-cast alloy and (b) as-spray formed alloy at 50 N at sliding speed of 3.0m/s

### 3.6 Discussion

The present investigation demonstrates that spray forming significantly modifies the microstructure and tribological behaviour of Al–30Pb bearing alloy. Rapid solidification during atomization refines the α-Al grains and produces a homogeneous dispersion of fine Pb particles, thereby eliminating the coarse segregated Pb network typically observed in conventionally cast alloys. This refined microstructure enhances the load-carrying capacity and facilitates the formation of a stable solid-lubricating film during sliding. Consequently, the spray-formed alloy exhibits lower wear rate, reduced coefficient of friction, and less severe surface damage under all investigated loading conditions. These findings are consistent with recent studies reporting that rapid solidification and uniform Pb dispersion substantially improve the wear performance of aluminium-based bearing alloys, confirming the effectiveness of spray forming as an advanced processing technique for tribological applications.

## 4. Conclusions

The present study investigated the influence of spray forming on the microstructure and tribological performance of Al–30Pb bearing alloy. Based on the experimental observations, the following conclusions can be drawn:

1. Spray forming successfully produced a refined and homogeneous microstructure with equiaxed α-Al grains and uniformly distributed fine Pb particles, in contrast to the coarse needle-like Pb morphology observed in the conventionally cast alloy.
2. Rapid solidification during spray forming effectively suppressed Pb segregation and minimized microstructural heterogeneity, resulting in improved material integrity and uniform phase distribution.
3. The wear rate of both alloys increased with increasing normal load and sliding velocity; however, the spray-formed Al–30Pb alloy consistently exhibited lower wear rates than the conventionally cast alloy under all test conditions.
4. The coefficient of friction of the spray-formed alloy was lower than that of the as-cast alloy due to the formation of a stable Pb-rich lubricating film, which reduced direct metal-to-metal contact during sliding.
5. Worn surface analysis revealed that the spray-formed alloy experienced only mild abrasion and limited plastic deformation, whereas the conventionally cast alloy exhibited severe adhesive wear, deep grooves, and delamination.
6. Overall, spray forming proved to be an effective processing technique for enhancing the microstructural characteristics and tribological performance of Al–30Pb bearing alloys, making them suitable for high-performance bearing applications in automotive and aerospace industries.

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