

INVESTIGATION OF HARDNESS AND MICROSTRUCTURE IN Al+Sn POWDER ALLOY COMPOSITES REINFORCED WITH RESIN

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Abstrak: Material komposit merupakan salah satu kelas utama alternatif rekayasa yang dikembangkan untuk menggantikan material konvensional yang semakin terbatas baik dari segi ketersediaan maupun kinerjanya. Di antara material konvensional yang dibahas dalam konteks ini adalah aluminium (Al) dan timah (Sn), yang secara tradisional dikenal memiliki densitas rendah, sifat ulet, serta ketahanan korosi yang baik. Penelitian ini bertujuan untuk mengevaluasi karakteristik kekerasan dan fitur mikrostruktur dari paduan komposit serbuk logam Al+Sn yang diperkuat dengan pengikat resin. Hasil pengamatan mikrostruktur menunjukkan adanya tiga fase penyusun yang berbeda, yaitu fase gabungan Al+Sn yang berwarna kekuningan, fase unsur Sn dengan tampilan logam cerah, serta cacat porositas yang tersebar pada matriks. Nilai kekerasan Brinell untuk berbagai komposisi spesimen berturut-turut adalah sebagai berikut: Al 50%–Sn 50% sebesar 51,67 N/mm²; Al 60%–Sn 40% sebesar 55,86 N/mm²; Al 70%–Sn 30% sebesar 64,69 N/mm²; Al 80%–Sn 20% sebesar 68,01 N/mm²; dan Al 90%–Sn 10% sebesar 64,77 N/mm². Hasil penelitian ini menunjukkan bahwa peningkatan proporsi aluminium dalam sistem paduan Al–Sn menghasilkan peningkatan kekerasan komposit secara bertahap.

Kata kunci: Penguat Resin, Uji Kekerasan, Mikrostruktur.

Abstract: Composite materials represent a prominent class of engineering alternatives developed to substitute conventional materials, which are increasingly constrained in terms of both availability and performance. Among the conventional materials addressed in this context are aluminum (Al) and tin (Sn), which are traditionally recognized for their low density, ductile behavior, and notable resistance to corrosion. The present study aims to evaluate the hardness characteristics and microstructural features of Al+Sn metal powder composite alloys reinforced with a resin binder. Microstructural examination revealed the presence of three distinct constituent phases: an Al+Sn combined phase exhibiting a yellowish coloration, an elemental Sn phase with a bright metallic appearance, and visible porosity defects distributed throughout the matrix. Corresponding Brinell hardness values for the various specimen compositions are as follows: Al 50%–Sn 50% recorded 51.67 N/mm²; Al 60%–Sn 40% recorded 55.86 N/mm²; Al 70%–Sn 30% recorded 64.69 N/mm²; Al 80%–Sn 20% recorded 68.01 N/mm²; and Al 90%–Sn 10% recorded 64.77 N/mm². These findings collectively indicate that an increase in the proportion of aluminum within the Al–Sn alloy system produces a progressive improvement in composite hardness.

Keywords: Resin Reinforcement, Hardness Testing, Microstructure

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INTRODUCTION

Rapid progress in materials science and engineering has intensified the demand for structural materials that combine superior mechanical performance with reduced weight and enhanced durability under corrosive and abrasive conditions. Conventional metallic materials, including pure metals, have progressively revealed inherent limitations in fulfilling these multifaceted requirements, both in terms of mechanical efficiency and resource sustainability. As a consequence, composite materials have attracted considerable research interest owing to their capacity to synergize the advantageous attributes of their constituent components (Bhagat, 2013).

Metal matrix composites (MMCs), particularly those based on aluminum, have experienced substantial advancement in recent decades. Aluminum exhibits favorable characteristics, including low mass density, satisfactory thermal conductivity, and inherent corrosion resistance. Nevertheless, unalloyed aluminum is limited by relatively modest hardness and insufficient wear resistance for demanding engineering service conditions. The incorporation of tin (Sn) as an alloying element offers a viable approach to address these shortcomings, given that tin possesses self-lubricating properties conducive to improving tribological performance (Confalonieri et al., 2020).

The combination of aluminum and tin in the form of powder-processed composite alloys offers substantial potential for producing materials with an optimized balance between mechanical properties and microstructural integrity. It has been established that the spatial distribution of Al and Sn phases within the composite microstructure exerts a governing influence on mechanical response, particularly with respect to hardness and wear behavior. A uniform and homogeneous phase distribution generally yields superior and more consistent mechanical properties (Khan et al., 2020).

Powder metallurgy (PM) has been widely adopted as a manufacturing technique for metallic composites, primarily because it affords precise control over compositional uniformity, particle dispersion, and porosity levels. This approach enables the effective consolidation of materials with substantially different melting points, such as Al and Sn, resulting in more homogeneous microstructures relative to those achievable through conventional casting processes (Shadangi et al., 2022; Chen et al., 2015). Furthermore, processing parameters, including compaction pressure and sintering temperature, are recognized to exert critical influence on the final density and hardness of the consolidated material (Rahimian et al., 2011). The role of reinforcing agents in composite development is equally significant. In this study, resin is employed as a

binding medium between metallic particles, serving to enhance interparticle cohesion and promote microstructural stability. The addition of resin is expected to influence both phase distribution and porosity formation, with consequential effects on the resulting mechanical properties, particularly hardness.

Hardness constitutes a fundamental mechanical parameter for evaluating material quality, especially in engineering applications that demand resistance against plastic deformation and surface degradation. The Brinell hardness test is widely applied for this purpose, as it offers macroscopically representative measurements of material mechanical behavior. Complementary microstructural analysis is essential to establish the relationships among composition, phase morphology, and mechanical response in a comprehensive manner (Jacob et al., 2015). Based on the foregoing considerations, research into Al+Sn powder alloy composites incorporating resin reinforcement is warranted to advance the understanding of their properties. This investigation is specifically oriented toward examining the hardness and microstructural characteristics of composites prepared with varying Al and Sn compositional ratios. The outcomes are expected to contribute meaningful insights into the composition–microstructure–property relationships of this material system, thereby supporting the broader development of aluminum-based composites for advanced engineering applications.

METHODS

Hardness evaluation was performed using the Brinell hardness testing method, which quantifies a material's resistance to permanent surface indentation by a hardened steel ball (indenter) pressed against the specimen surface under a defined load. The Brinell method is particularly suited for materials exhibiting relatively rough surfaces & is commonly applied over load ranges from 500 to 3000 kgf. The indenter employed in this technique is typically a hardened and plated steel ball or a ball manufactured from tungsten carbide, selected based on the material hardness range being tested

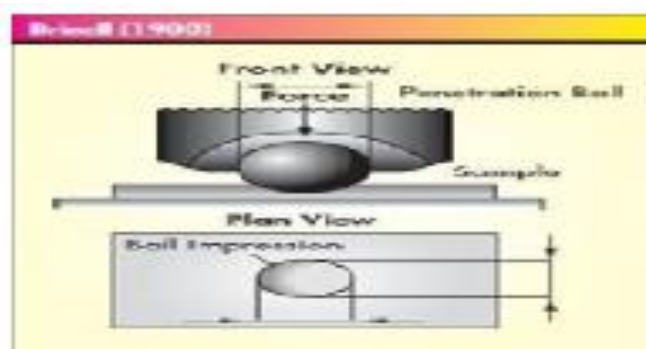


Figure 1. Schematic of the Brinell hardness test configuration

DISCUSSION

The hardness test results presented in Figure 2 reveal that the Al–Sn alloy specimens prepared across the compositional range of Al 50%–Sn 50%, Al 60%–Sn 40%, Al 70%–Sn 30%, Al 80%–Sn 20%, and Al 90%–Sn 10% exhibited distinctly different hardness values. Each specimen was subjected to seven indentation points, yielding a range of hardness readings. The average hardness for each composition was computed by aggregating all measured data points and calculating the arithmetic mean. The resulting average hardness values are: Al 50%–Sn 50%: 51.67 N/mm²; Al 60%–Sn 40%: 55.86 N/mm²; Al 70%–Sn 30%: 64.69 N/mm²; Al 80%–Sn 20%: 68.01 N/mm²; and Al 90%–Sn 10%: 64.77 N/mm². These averaged values are considered sufficiently representative of the bulk mechanical behavior of each tested material.

Titik penekanan	Beban (N)	Nilai kekerasan HB (N/mm ²)				
		Al 50 % - Sn 50 %	Al 60 % - Sn 40 %	Al 70% - Sn30%	Al 80% - Sn20%	Al 90% - Sn10%
1	613	53.8	54.4	64.1	67.8	67
2		44.1	54	63.7	67.1	64.1
3		50	57.2	62.8	69.1	65.7
4		55	55.8	68.4	69.1	64.7
5		51.7	54.4	61.8	68.4	63.5
6		55.8	57.5	67.3	67	65.7
7		51.3	57.7	64.7	67.6	62.7
Nilai kekerasan rata-rata \bar{x}		51.67	55.86	64.69	68.01	64.77

Figure 2. Hardness comparison of resin-reinforced Al–Sn composites.

Hardness Test Graph Analysis

An examination of the hardness graph indicates notable variation across the indentation points for each specimen composition. The Al 50%–Sn 50% specimen recorded a mean hardness of 51.67 N/mm², while the Al 60%–Sn 40% composition yielded a mean value of 55.86 N/mm². Progressive increases were observed with higher aluminum fractions: Al 70%–Sn 30% registered 64.69 N/mm², and Al 80%–Sn 20% achieved the maximum mean hardness of 68.01 N/mm². A slight reduction was then observed in the Al 90%–Sn 10% composition, which recorded a mean hardness of 65.70 N/mm².

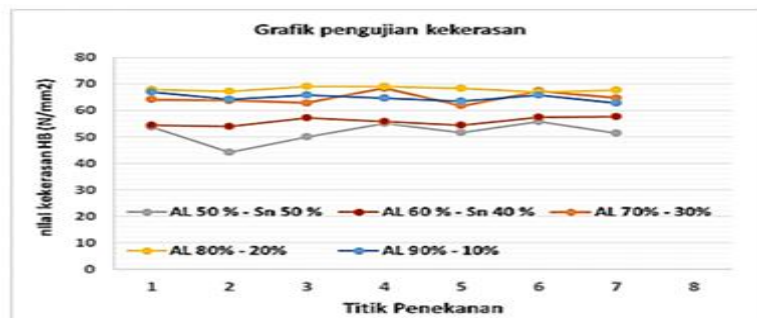


Figure 3. Brinell hardness test results graph

Microstructural Analysis – Al 50%–Sn 50% Composite

Optical microstructural examination of the Al 50%–Sn 50% specimen (Figure 4) at 200× magnification disclosed the presence of porosity defects alongside two distinguishable constituent phases. The first phase, corresponding to the combined Al+Sn matrix, presents a yellowish hue in the form of fine granular structures. The second phase, attributable to elemental Sn, appears as bright, lustrous white regions. In this composition, both Al and Sn phases are present in nearly balanced proportions owing to their equal mass fractions during processing. The relatively balanced phase distribution results in a material of moderate hardness with a tendency toward brittle behavior.

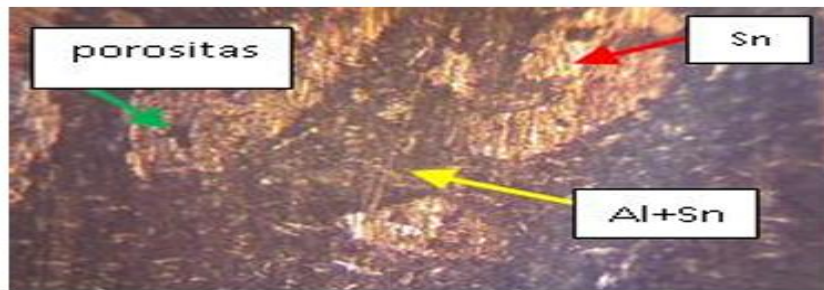


Figure 4. Microstructure of Al–Sn powder alloy composite (Al 50%–Sn 50%), 200× magnification

Microstructural Analysis – Al 60%–Sn 40% Composite

Microstructural observation of the Al 60%–Sn 40% specimen (Figure 5) at 200× magnification similarly reveals porosity defects and the presence of two distinct phases: the Al+Sn phase with its characteristic yellowish, fine-grained morphology, and the elemental Sn phase exhibiting a bright white appearance. Although the Al content exceeds that of Sn in this composition, the Sn phase appears nearly in balance within the observed microstructure due to partial dissolution or sedimentation occurring during processing. The hardness of this composition shows measurable improvement relative to the Al 50%–Sn 50% specimen.



Figure 5. Microstructure of Al–Sn powder alloy composite (Al 60%–Sn 40%), 200× magnification

Microstructural Analysis – Al 70%–Sn 30% Composite

The microstructure of the Al 70%–Sn 30% specimen (Figure 6) at 200× magnification displays porosity defects and two identifiable phases analogous to those observed in lower aluminum content specimens. The Al+Sn combined phase retains its yellowish, fine-grained character, while the elemental Sn phase continues to appear as bright white areas. The predominance of the Al phase over Sn is evident, yet the Sn phase distribution appears relatively uniform due to dissolution and settling behavior during consolidation. This compositional configuration further contributes to an increase in composite hardness.

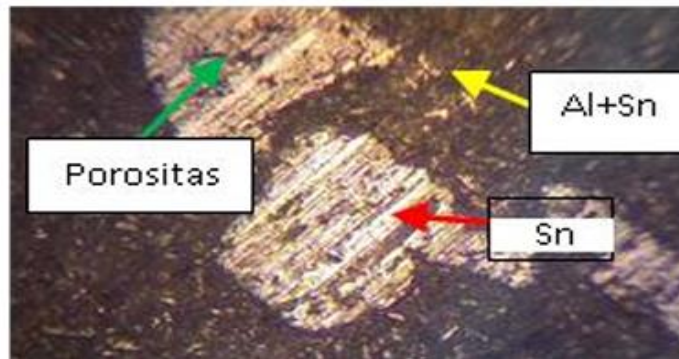


Figure 6. Microstructure of Al–Sn powder alloy composite (Al 70%–Sn 30%), 200× magnification

Microstructural Analysis – Al 80%–Sn 20% Composite

Examination of the Al 80%–Sn 20% specimen (Figure 7) at 200× magnification reveals the consistent presence of porosity and two primary phases. The Al+Sn phase appears as a yellowish, fine-grained matrix, while elemental Sn forms bright white regions. In this composition, the Al phase distinctly dominates the microstructure, and the Sn phase is markedly reduced in volume fraction compared to lower-tin compositions. The diminished Sn content contributes to enhanced matrix continuity and a measurable increase in composite hardness relative to specimens with higher tin proportions.

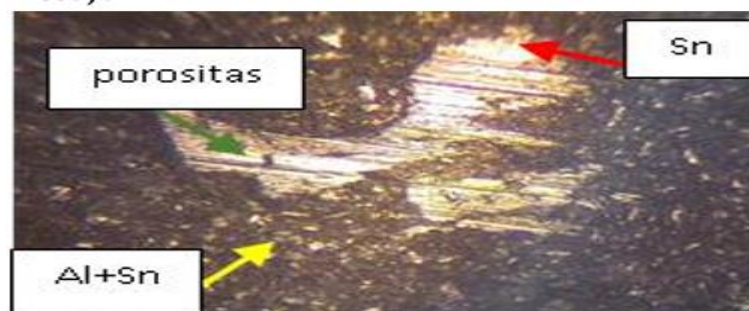


Figure 7. Microstructure of Al–Sn powder alloy composite (Al 80%–Sn 20%), 200× magnification

Microstructural Analysis – Al 90%–Sn 10% Composite

The microstructural observation of the Al 90%–Sn 10% specimen (Figure 8) at 200× magnification once again identifies porosity defects alongside the two characteristic phases: the Al+Sn combined phase appearing yellowish and fine-grained, and the elemental Sn phase appearing as bright white inclusions. The volume fraction of the Sn phase is noticeably minimal compared to the predominant Al matrix. The significantly reduced tin content diminishes the size of Sn grain clusters, which is associated with an increase in material hardness, consistent with the Hall–Petch relationship between grain size and mechanical strength.

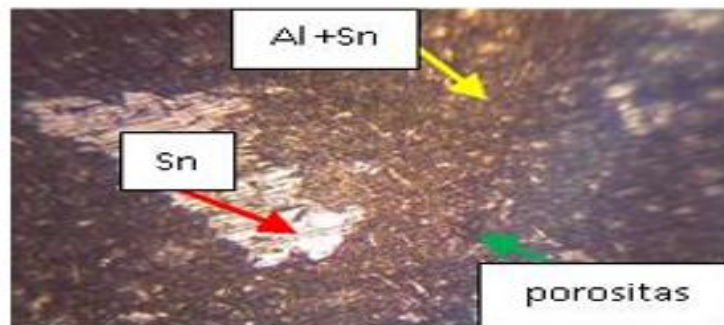


Figure 8. Microstructure of Al–Sn powder alloy composite (Al 90%–Sn 10%), 200× magnification

CONCLUSION

Based on the integrated analysis of hardness data and microstructural observations for the Al–Sn powder alloy composites, the following conclusions are drawn. Brinell hardness testing revealed that the Al 50%–Sn 50% specimen exhibited the lowest mean hardness among all tested compositions, recording 51.70 BHN, reflecting the influence of a balanced and softer Sn-rich phase distribution. The Al 70%–Sn 30% and Al 90%–Sn 10% specimens yielded comparable mean hardness values of 64.69 BHN and 64.77 BHN, respectively, suggesting that within this compositional range, further reduction in Sn content beyond 30% produces limited incremental hardness gains in isolation. The highest mean hardness of 68.01 BHN was recorded for the Al 80%–Sn 20% composition, demonstrating that this ratio represents an optimal balance between Al matrix dominance and Sn phase reinforcement within the investigated compositional range.

Microstructural analysis further established that the Al 50%–Sn 50% cast specimen exhibited the largest Sn grain diameters, whereas the Al 90%–Sn 10% composition produced the smallest Sn grain sizes. This inverse relationship between Sn grain diameter and composite hardness confirms that larger grain clusters correspond to

reduced hardness and softer material behavior, while finer Sn grain distributions promote increased hardness accompanied by a greater tendency toward brittleness. These findings collectively underscore the critical role of compositional control in tailoring the mechanical performance of resin-reinforced Al–Sn powder alloy composites.

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