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Retraction

Retracted: Impact of BN and WC Particulate Reinforcements on Mechanical Properties and Damage Development of Al-2048 Metal Matrix Composites

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] T. Sivakumar, C. Udagani, M. Sivaranjani et al., "Impact of BN and WC Particulate Reinforcements on Mechanical Properties and Damage Development of Al-2048 Metal Matrix Composites," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 2286713, 9 pages, 2022.

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Research Article

Impact of BN and WC Particulate Reinforcements on Mechanical Properties and Damage Development of Al-2048 Metal Matrix Composites

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The primary goal of this work is to evaluate how BN and WC particles affect the mechanical properties and damage development behaviours of aluminum alloy-2048. Heat treatments for composites are also being investigated to improve mechanical properties. Tensile experiments reveal that BN particle reinforcement outperforms WC reinforcement in strength and flexibility for composites. T4 treatment, rather than traditional peak-aging treatment, is recommended for the composites (T6). The particle size distribution in 10v% WC/Al-2048 is the best in the three composites with the largest size of 16 μm and 80% of particles are from 6 to 10 μm. Tensile tests illustrate that 15v% BN/Al-2048 composite demonstrates a 9 and 14% rise in its ultimate tensile stress and 28 and 120% increases in its elongation. T4 heat treatment with an additional 0.6 percent prestrain can produce composites with the same UTS and 0.2 percent proof stress as T6 treatment, but the ultimate elongation below T4 treatment is over 100 percent more than that under T6 treatment. To make sense of the test results, an observation of the damage evolution behaviors of the reinforcing particles provides a concept that the composites' strength is primarily determined by the balance between the reinforcing particles sharing the load and creating strain discontinuity in the matrix. The fraction of broken particles in the 20v% WC/Al-2048 composite as a function of strain is much higher than that in the 15v% BN/Al-2048 composite. Because of their tolerance for substantial strain at the interface, maximum K1c, and moderate thermal extension, BN elements can share a lot of loads and provide more excellent reinforcement than WC particles in terms of composite strength and flexibility.

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1. Introduction

MMCs are highly designed metals with greater durability, abrasion, and outstanding dampening properties, rendering them appropriate for a broad array of uses in mobility, gadgets, aircraft, and marine.

Aluminum alloy bonded with hyperparticles for increased strength and toughness. Aluminum composites provide a consumer with the benefits of lighter yet stable properties. Aluminum composites are a family of materials which have so far been effective at achieving the majority of the stringent standards in applications requiring low density, high stiffness, and intermediate tenacity. Particulate-reinforced metal matrix composites combine short compactness, increased toughness and stiffness, isotropic properties, and superior wear resistance [1]. Several composites, such as matrix alloy, preparation type, aged condition, capacity portion of reinforcements, element size, particle size distribution, type of reinforcement material, and the integration situation among matrix and particulate, could all have an impact on physical behavior [2, 3]. Many aluminum alloys, such as 2014, 7075, 6082, and 6061, reinforced with ceramic and ash particles have been investigated extensively [4, 5]. Al-2048 reinforced with ceramic particles has been developed to meet the requirement of some possible applications at high temperature, for instance, automotive brake callipers, conrods, and pistons, or supersonic aerospace airframe constructions [6–8]. The BN particle reinforced Al-2048 MMCs have also been the subject of a few studies. It is desirable to use spray deposition for 2048 alloy because it reduces the dispersions of iron and nickel [9]. This MMC has a lower potential cost as compared to high strength aluminum alloys. Because of the addition of the reinforcing ceramic phase, the tensile ductility and breaking toughness of PR-MMCs are far lower than those of their matrix alloys. As a result, many research efforts have been concerned with the analysis of the distortion and discontent methodology of PR-MMCs in terms of improving them explicitly for transportation sectors. [10–12].

Two kinds of particulate reinforcements, BN and WC, have been widely used in the development of PR-MMCs [13]. Many investigations on BN and WC particulate-reinforced MMCs are carried out independently so that the experimental results cannot be compared effectively due to the differences in the matrix alloys and in processing methods used by individual researchers [9]. Therefore, not much has been known about the effect of different type of reinforcing particles between BN and WC on the composite properties unfortunately. Paper [14] studied the difference between BN and WC particulate-reinforced Al-Cu alloys on the fortification types on the microstructure of the composites. The outcomes also showed that the occurrence of particulate fortification (both BN and WC with a mean size of 3 μm) in the Al alloy composite (AA2519) could not help in refining its toughness [15, 16]. Three Al-2048 matrix composites reinforced by particulate BN (with a median of 9 μm) and WC (with mean size of 8 μm or 15 μm), respectively, were manufactured by a same spray forming process and by exactly same thermomechanical processes afterwards in the present study [17–20]. The comparisons of mechanical properties and damage evolution behaviors during straining between the composites were investigated in order to have further understanding of the strengthening and failure mechanisms of the composites [9].

Although there have been some researchers reported in the literature about effects of reinforcing particles on the aging behaviors of the aluminum alloy matrix PR-MMCs, the T6 heat treatment which is the conventional heat treatment for aluminum alloys is popularly used for the composites in nearly all the studies and applications [21]. Heat treatments for the composites used in this study are also investigated to enhance their mechanical behaviour. The strengthening mechanisms in PR-MMCs are popularly believed in the micromechanical models [22]. These representations are concerted on the belongings of particulate fortification on solidification of the composite, i.e., the effects likewise increasing displacement thickness and resulting in fine scrap size. This conclusion is supported by numerous studies, which show that particulate reinforcement increases the strength of PR-MMCs with soft matrices but not with hard matrices. PR-MMCs' strength is largely determined by a balance between reinforcing particles sharing the load and creating strain discontinuities in their matrix, according to the cracking behaviour of reinforcing particles [23, 24]. This theory is used to explain the test results in this study, which show that hard matrix alloys are strengthened over their matrix alloys.

2. Materials and Experimental Procedure

This investigation made use of three PR-MMCs and an Al-2048 alloy. Boron nitride is a ceramic compound material that really has grown in popularity primarily because of its excellent heat conductivity, greasing properties, chemical inertness, mechanical strength, oxidation resistance, and nonwettability. BN/Al-2048 is a composite with a nominal 15% volume proportion of BN particle reinforcement. WC particle reinforced Al-2048 matrix composites with a volume fraction of 10% and 20% are referred to as 10v percent WC/Al-2048 and 20v percent WC/Al-2048. A spray-forming-deposition technique was used to create the tested materials. Ball grinding and sieving with a nominal grain size of 10 m were utilised for the production of commercial BN powder. An electrical melting technique and subsequent ball grinding and sieving result in WC powder with a nominal grain size of 10 μm, which is also available commercially. Chemical investigation identified the Al-2048 matrix as Al-2.5w% Cu-1.5w% Mg-1.1w% Ni-1.1w% Fe as its composition. To make bars with a diameter of 40×100 mm, the ingots were heated to the temperature of 5100°C and then cooled by air (as extruded). A two-hour solution treatment at 530°C followed by machining into cylindrical tensile dumbbell specimens with 5 mm diameter and 25 gauge length completed the procedure. As part of a study to see how particulate-reinforced Al-2048 composites age over time, they were aged at 200°C (peak-aged condition, T6) for 20 hours (BN and WC).

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There was no additional use of artificial ageing for the others (T4). On the CSS servoelectric testing machine, the applied strain rate was $3:5\times10^{5}$ Sec^{-1} for all tensile tests. Structural characteristics of the materials were measured using extensometers and strain gauges of two different types during straining. An unloading/reloading process was used to generate a straight stress-strain line for higher measurement precision, while avoiding any damage to the reinforcements during the procedure. Using repeated unloading and reloading at room temperature, the elastic modulus of the composites was reduced during tensile straining as a means of assessing damage progression in the composites. Composite damage evolution during deformation cannot be studied by measuring the percentage of broken BN elements on the sectioned samples after several strains of tensile stress. The damage evolution in terms of the percentage of broken elements as a function of strain can then be investigated by the local fraction of broken particles matching the local actual strain in the necking area of a single tensile cracked specimen. Using a tensile test as shown in Figure 1, it is possible to determine the amount of plastic strain in the necked region. It was necessary to magnify tensile samples in order to correctly estimate their local diameters before conducting the tensile test. To measure the local diameter of the samples, the two broken halves of the specimens were aligned and adhered together with a very small drop of glue after the tensile test was completed for one second. Assuming that D_o and D, the diameters of the specimens, are known before and after the test, local true strain can be calculated using this formula: $T=-2\ln(D/D_o)$. Before polishing, broken samples are cut longitudinally along the stress axis using spark corrosion to stop additional mechanical mutilation.

3. Results and Discussion

3.1. Size Distribution of Reinforcing Particles. The observation of the composites after extrusion reveals that all three composites present rather good homogeneous reinforcement distribution. However, the size of reinforcing particles spreads a large range owing to the commercial ceramic powder made by low cost processes. 108 measurements dispersed frequently over the comprehensive sample surface of 60 mm^2 were selected to control the local reinforcement volume fraction and the particle geometry significance in these three composites. Each measured area is a $0:1\times0:083$ mm rectangle.

Figure 2 shows the distribution of the diameter of particulate reinforcement in the three tested composites in the as-extruded condition. The mean volume fractions in 15v% BN/Al-2048, 10v% WC/Al-2048, and 20v% WC/Al-2048 were measured as 15.8, 10.9, and 20.3%, respectively, which are close to the nominal specifications. The particle sizes in 15v% BN/Al-2048 are distributed in a large range up to 26 μm, but size of 85% particles ranges from 6 to 14 μm. The particle size distribution in 10v% WC/Al-2048 is the best in the three composites with largest size of 16 μm and particles of the size of 80% are from 6 to 10 μm. Distribution of particle size in 20v% WC/Al-2048 is the poorest in three

Figure 1: Tensile testing setup.

composites with particle size up to 34 μm and 45% reinforcing particles are larger than 16 μm. It is not surprising that distribution and size distribution of particulate reinforcements among the three examined composites are quite similar because of same processing, same matrix alloy, and same thermomechanical procedures. Therefore, the difference of mechanical properties caused by the differences in cluster and size distribution of reinforcement among the three tested composites would be small and has been neglected by this study. But, the mean particle size of 20v% WC/Al-2048 is quite different from the other two composites and its effect on the properties will be discussed later.

3.2. Composite Mechanical Qualities as an Effect of Heat Treatment. Mechanical characteristics of the materials tested at the room temperature under different heat treatments are listed. Every test datum comes from the average of at least two individual tests if the two tests yield a difference less than 3% between them; otherwise, a third test would be carried out. The results in the figures indicate that different heat treatments have little effect on elastic modulus for the composites, but can change the 0.2% proof stress of the mixtures dramatically. Conventional T6 treatment produces higher 0.2% proof stress but lower final elongation compared with the T4 heat treatment for both the matrix alloy and the composites. T4 treatment looks very interesting. Al-2048 matrix alloy has no effect of natural aging as the properties of the composite by natural aging for one week were tested. The tested data also show that the T4 heat treatment results in low UTS for Al-2048 matrix alloy compared with the T6 treatment. However, the T4 treatment for the composites makes their ultimate tensile strength (UTS) as high as T6 treatment. UTS and final elongation of the three composites under T4 and T6 treatments are shown in Figure 3.

Thus, the T4 treatment is better than the conventional T6 treatment for the composites. The T4 treatment does not look good if an application requires high 0.2% proof stress.

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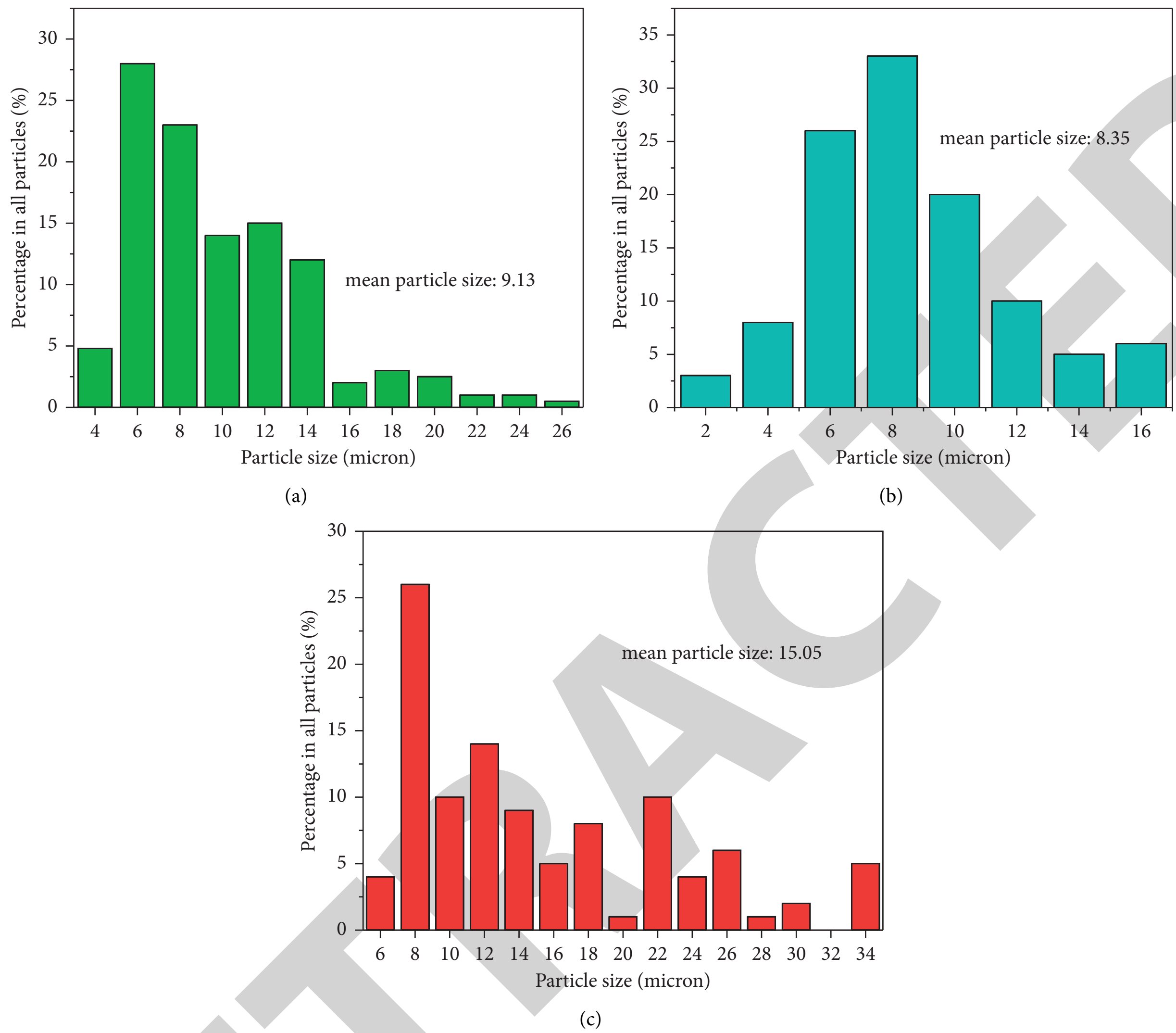

Figure 2: Size distribution of reinforcing particles in the composites: (a) 15v% BN/Al-2048, (b) 10v% WC/Al-2048, and (c) 20v% WC/Al-2048.

However, if composite in T4 state is given some prestrain, its 0.2% proof stress can be raised to a higher level. If the T4 composite is given a 0.6% prestrain, its subsequent 0.2% proof stress will be the same as the T6 composite; i.e., 0.8% proof stress of the T4 composite equals 0.2% proof stress of the T6 composite. The subsequent final elongation of the T4 composite should now be the tested elongation (8.24%) reduced by the prestrain of 0.6% which is still 124% larger than that of the T6 composite (3.4%). Therefore, T4 treatment in addition to a 0.6% prestrain is still the best treatment for the composites in the applications requiring a high yield strength. It can be concluded that the T4 heat treatment is more suitable for the composites than the regular T6 approach, though the T6 treatment is the best for the matrix alloy. The work hardening rate of a composite affects its 0.2 percent proof stress significantly, but with no effect on its UTS. The T6 heat treatment differs from the T4 treatment only in the fact that the T6 treatment produces precipitates in the matrices of the composites. It is the precipitates which strengthen the matrix of the composite, increase the work hardening rate, and lead to high 0.2 percent proof stress of the composites. The precipitates also decrease ductility of the matrix and result in the low final elongation of the composites. The T4 and T6 heat treatments make no difference on UTS of the composites, which implies that it is the reinforcing particles which contribute to high UTS of the composites. Further discussions on strengthening mechanisms will be given in Section 3.5 to interpret the test results.

3.3. Influence of Reinforcement Type on Mechanical Behaviour of Composites. Though comparison of mechanical behaviour of the composites with different types of reinforcement leads to the same conclusions under both T4 and T6 treatments, only the composites under T4 treatment are selected to make the comparison because the study in last section suggests the T4 treatment being the best treatment for the composites. Stress-strain curves of three tested composites under T4 heat treatment are given in Figure 4 to compare the outcome of various types of reinforcements on

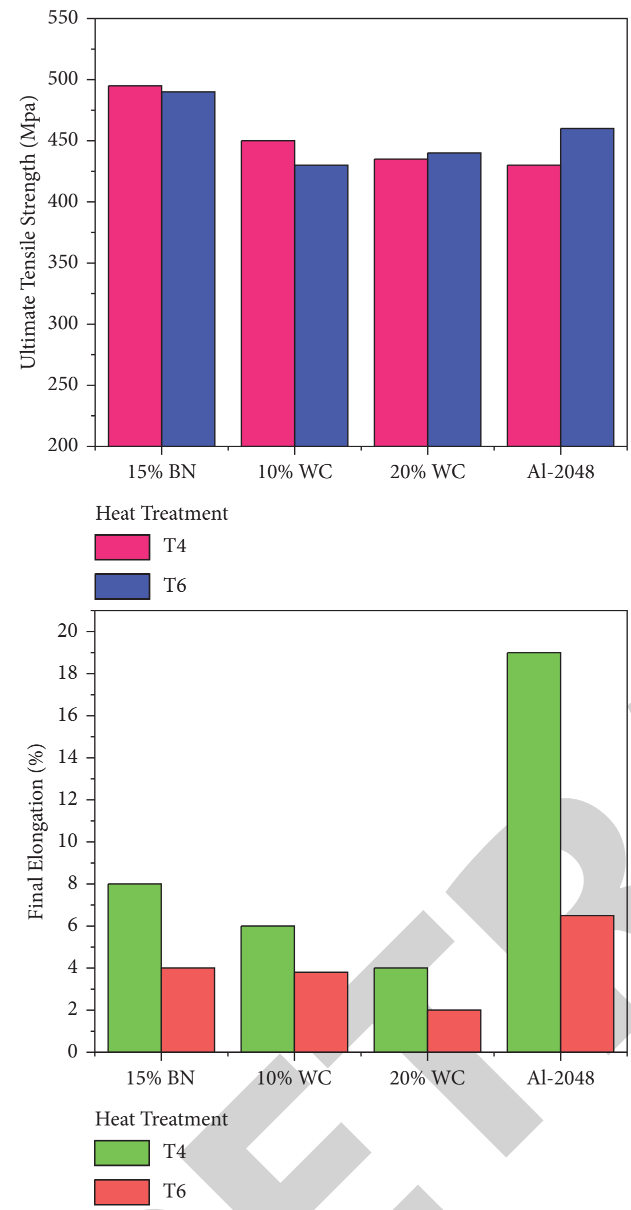

Figure 3: Comparison of UTS and final elongation of the composites with different heat treatments at the room temperature.

the tensile properties. It is shown that the 15v% BN/Al-2048 composite demonstrates 9 and 14% increases in UTS and 28 and 120% increases in final elongation over the 10 v and 20v % WC/Al-2048 composites, respectively. It is not easy to fabricate the composites with same volume fraction and same particle size of different reinforcements for theoretical study using industrial facilities, but convincing conclusions can still be deduced based on the above limited test results. It was reported that increasing particle size in a range from 8 μm to 30 μm can result in an increase in the strength of some PR-MMCs. More generally, reduction of the strength is not significantly affected by the particle size of reinforcement at the range of 10~20 μm for most matrix alloys at a volume fraction of reinforcement from 10% to 30%.

The UTS of 15v% BN/Al-2048 is 9% higher than that of 10v% WC/Al-2048 and 14% than 20v% WC/Al-2048, so it

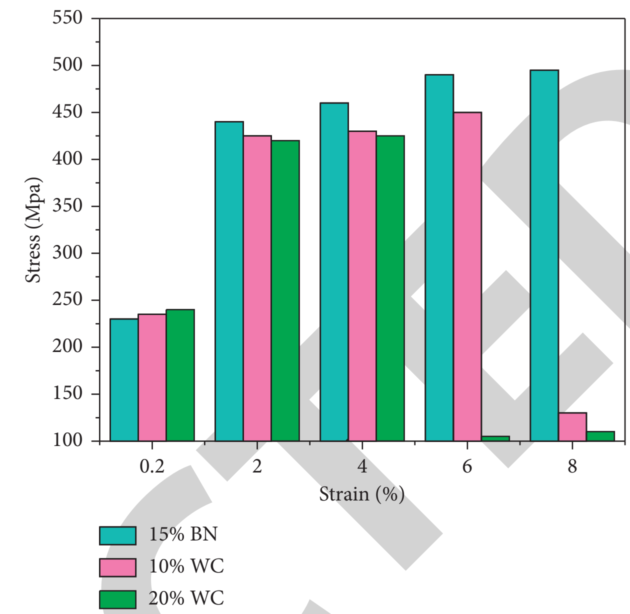

Figure 4: Stress-strain plots for all the three tested composites under T4 heat treatment.

can be seen that the BN particles have advantage over the WC particles in increasing strength of the composite, though it is neglected that the particle size is not the same among the three composites. It has been shown that ductility of a PR-MMC always decreases with increasing the volume fraction or/and the particle size. The volume fraction of reinforcement in 15v% BN/Al-2048 is higher than that in 10v% WC/Al-2048 and the average size of reinforcement in 15v% BN/Al-2048 is the about same as that in the latter. Nevertheless, 15v% BN/Al-2048 presents a much larger final elongation over that of 10v% WC/Al-2048. Therefore, it can be concluded that BN reinforcement has advantage of WC reinforcement in both strength and ductility for composite. This is a rather significant cognition. The reasons may rely on reinforcement fracture behavior during composite straining, i.e., the strengthening mechanisms which will be further discussed.

From the data, 20v% WC/Al-2048 shows the highest elastic modulus due to its highest volume fraction of reinforcements among the three composites. The modulus of elasticity of the 15v% BN/AA-2048 composite is only a little higher than that of the 10v% WC/Al-2048 composite. This indicates that BN particles have the same effect on elastic modulus as WC though WC shows a little better effect on stiffness of the composites than BN. The 20v% WC/Al-2048 with high volume fraction and larger element size of the reinforcement increases nothing in its UTS over 10v% WC/Al-2048, but loses nearly a half in its final elongation. This suggests that WC reinforcement is not good at increasing the strength of the Al-2048 alloy even with a 20% volume fraction and the severe ductility deterioration may affect the strength in turn.

3.4. Damage Evolution of the Composites. Broken reinforcing particles have almost not been found in all three composites after extrusion, and therefore, the effect of the damage

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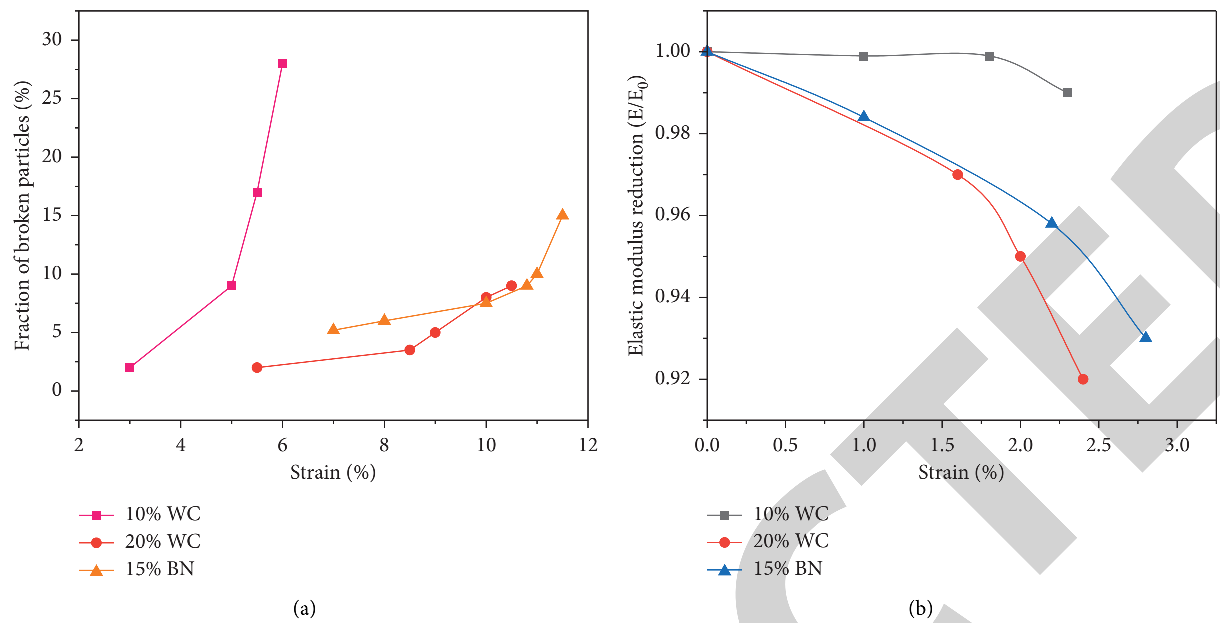

Figure 5: Damage evolution in the composites under T4 heat treatments during tensile straining shown by two ways: (a) by the fraction of broken elements as a function of tensile strains and (b) by elastic modulus reduction normalised by the modulus at zero strain during tensile straining.

particles which may occur during composite production on the subsequent damage evolution during mechanical testing of the AMCs has been neglected in this study. Damage evolution examinations were in agreement in only the composites under T4 heat treatment for the same reason that the T4 treatment is most suitable to the composites. The observation on longitudinal section of tensile fractured specimens beneath the fracture surface exposes that there are quite many reinforcing particles cracked in whole necking region, and the farther from the fracture surface, the fewer the cracked particles. The crack of the reinforcement is the only damage mode during deformation except a few shattered and micro voids at particle cluster which can be found just beneath fracture surface. The farther a position is from the fracture surface, the less the strain at that position is. Particles cracking and plastic strain are shown to be linked by analysing at least 10 randomized observations across the material at the same strain. The three composites tested under the T4 treatment showed damage progression in the proportion of fractured particles as a function of tensile stresses. It can be seen that the numbers of broken reinforcements in all the three composites are increased with an increase in plastic strain. During tensile deformation, the elastic modulus decreases, allowing us to track the progression of the damage. Using the modulus at zero strain as a reference point, we calculated the modulus reduction data for all composites treated with the T4 treatment. For example, the percentage of broken particles in 10% WC/Al-2048 is lower than that in 15% BN/Al-2048 and 20% WC as a function of strain can be seen in Figure 5. This is consistent with the smallest reduction in E/E0 of 10v% WC/Al-2048 during straining. It can also be seen that the rate of reduction in E/E0 of 20v% WC/Al-2048 is faster than that of 15v% BN/Al-2048. The fraction of broken particles in the 20v% WC/Al-2048 composite as a function of strain is much higher than that in the 15v% BN/Al-2048 composite. Therefore, the reduction in elastic modulus during straining as a damage parameter can be explained qualitatively by the increasing broken reinforcements.

3.5. Strengthening Mechanisms in the Composites. The micromechanical models consider that the increasing in strength of a composite comes only from the increasing in the strength of the matrix caused by the reinforcements; i.e., suppose that the stress in the reinforcements is always the same in the matrix. Our experimental results show that any of the three tested composites under the T4 treatment presents same UTS as under the T6 treatment. The only difference between a T4 composite and its T6 composite is the much softer matrix of the T4 composite. Thus, UTS of the T4 composite should be much lower than that of the T6 composite according to the micromechanical models. The continuum models such as shear lag theory and finite element numerical analysis would fail to explain the high UTS of the T4 composite too if constitutional law of the matrix alloy is used because UTS of the matrix alloy under the T4 treatment is much lower than T6 treatment.

Observation of reinforcements cracking behaviors after tensile fractured beneath fracture surface may reveal messages on the strengthening mechanisms in the composites. The fraction of broken particles is a function of strain in the 15v% BN/Al-2048 composite under the T4 and the T6 heat treatments, respectively, and the 10v% WC/Al-2048 composites. There are many reinforcing particles broken far away from the fracture surface, i.e., at very small strain. Strength of the BN or WC particles in the composites is at least over 1000 MPa and should be about 2000 MPa in

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average and much higher than that of the matrix alloy. There exist many broken reinforcing particles far away from the fracture surface, indicating that the stress in the particles is much higher than in the matrix long before tensile fracture. A theory is suggested to interpret the test results that the particulate reinforcements contribute to the strength of a composite mainly by sharing a large part of the total load on the composite. The theory is based on the idea that the strengthening on the composites comes from the reinforcements themselves rather than their effects on increasing the strength of the matrix.

According to Eshelby's equivalent inclusion model, the stress in an elastic particle imbedded in an infinite plastic matrix, σ_p can be expressed by $\sigma_p = X\varepsilon$. And ε is defined as unrelaxed far field strain. In present case, ε can be defined as the accommodation strain which comes from the mismatch strain between the particle and the matrix during composite deformation. Therefore, the BN particles in the 15v% BN/Al-2048 composite under the T4 treatment should share a much larger quotient of the total load on the composite to compensate its soft matrix to result in the same UTS as the composite under the T6 treatment. The particles would share a large load provided a large accommodation strain be located at the interface between the particles and the matrix and at the matrix closely surrounding the particle. In fact, if all the particles in the composite sustain a load close to their strength, the UTS of the composite under the T4 treatment can be as high as 662 MPa according to the rule of mixtures which is much higher than the measured value of 491 MPa. The UTS of the composite is not so high because either the interface cannot accommodate a larger accommodation strain without debonding or the mismatch strain is relaxed plastically in the matrix failing to build up an accommodation strain around the particle large enough to transfer load.

Al-2048 reinforced by BN particles improves both strength and ductility over that reinforced by WC particles. It can be seen by comparing that there are much more broken reinforcing particles in the 15v% BN/Al-2048 composite than in the 10v% WC/Al-2048 composite after tensile test. This indicates that BN particles sustain a much larger load than WC particles in the view of statistics if stress distribution in the two composites is believed to be similar. The assumption is based on the results in the 15v% BN/Al-2048 curve which is very similar to the 10v% WC/Al-2048 curve. Therefore, UTS of the BN particulate-reinforced composite is higher than that of the WC reinforced composite with the same matrix, which implies that the BN interface has better ability to accommodate a large mismatch strain without debonding and strain relaxing than the WC interface. Moreover, fracture toughness K1c of BN values is typically 4 MPa $m^{1/2}$ whereas the typical value of WC is 2.5 MPa $m^{1/2}$ and better toughness of BN particles is another reason for the good reinforcing effects. Finally, lower coefficient of thermal expansion (CTE) of BN particles makes a larger difference in CTE from the Al-2048 matrix than WC particles which results in a higher dislocation density in the matrix around the BN particles. Dislocation network would make the bond between BN particles and the matrix stronger and would help the load transfer. The high dislocation density increases the matrix strength and also helps to spread the tensile straining over whole composite which would result in high elongation in return.

However, it has to be explained by the above load transfer theory that there are more broken reinforcing particles in 20v% WC/Al-2048 than in 15v% BN/Al-2048. Meanwhile, UTS of 20v% WC/Al-2048 is much less than that of 15v% BN/Al-2048. That the 20v% WC/Al-2048 curve is very different from the 15v% BN/Al-2048 curve indicates a different stress distribution in the two composites during straining so that more broken particles in 20v% WC/Al-2048 do not mean higher load in the WC particles in average than in the BN particles. The broken particles in the 20v% WC/Al-2048 composite are mainly concentrated at the high strain region and there are nearly no broken particles at the low strains; i.e., there is no a platform on the curve. Many localized broken reinforcing particles at the final fracture stage in the 20v% WC/Al-2048 composite imply that the load in a WC particle can reach its strength to break it only at the position where the microvoids coalesce into a fracture surface. Therefore, the UTS of 20v% WC/Al-2048 would be still low without a high load in all the WC particles in average. Particulate reinforcement has a potential to share load but it also has disadvantage of making strain discontinuity in the matrix. The severe strain discontinuity in the matrix caused by the WC particles makes the 20v% WC/Al-2048 a very low final elongation, which means a premature fracture during tensile test. The premature fracture does not allow the matrix to produce a mismatch strain to the particles large enough to transfer a sufficient load from the matrix to all the particles. Therefore, the UTS of 20v% WC/Al-2048 is very low and in that case, the ductility rather than the strength of a matrix plays an important role in increasing the strength of a composite. This can also explain the fact in tested results which reveals that the UTS of the both composites reinforced by WC particles in the T6 condition is less than that of the matrix alloy in the T6 condition, but the UTS of 15v% BN/Al-2048 is higher than that of the matrix alloy.

Decreasing the size of the reinforcing particles can result in an increase in the strength of PR-MMCs in terms of dispersion strengthening. However, some researches have confirmed that the strength of PR-MMCs increases with increasing the reinforcement size when the size is larger than a specific value. This together with our experiments imply that the micromechanisms play an important role on the strengthening for small reinforcing particles in soft matrix, but the load transfer mechanism is the dominant factor for intermediate reinforcement size. On the other hand, the mismatch strain cannot be accommodated at the interface between the particles and the matrix when the reinforcement size is very large, and then, load transfer fails so that the strength of the composite decreases with increasing the size of reinforcement. The specific size values for the strengthening mechanism transformation vary according to different systems and can be calculated by load transfer models such as Eshelby approach and shear lag theory, which would result in the optimal reinforcement design.

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4. Conclusions

(1) Tensile tests show that 15v% BN/Al-2048 composite demonstrates 9 and 14% increases in its UTS and 28 and 120% increases in its elongation over the 10v and 20v% WC/Al-2048 composite, respectively. When it comes to the properties of PR-MMCs, BN reinforcement is superior to WC reinforcement. But BN particles present a slightly weak effect on increasing the elastic modulus of the composites than WC particles.

(2) UTS of the composites reinforced by both BN and WC particles under T4 treatment are similar to those under T6 treatment, respectively. This difference in final elongation between T4 and T6 treatment is over 100%. T4 treatment is recommended instead of conventional peak-aging for composites (T6). Adding 0.6 percent prestrain to a T4 heat treatment increases the composites' 0.2 percent proof stress to a level comparable to T6 treatment.

(3) All three tested composites show reinforcing particles damaging gradually during tensile straining. The elastic modulus of the composites has decreased due to the cracking of reinforcing particles.

(4) Tensile test results of composites with different types of reinforcing particles and various heat treatments can only be interpreted by the theory that a composite's strength is primarily determined by the balance between reinforcing particles sharing the load and creating strain discontinuity of the matrix.

(5) T4 heat treatment makes the composite more significant final elongation than T6 treatment due to the flexible and soft matrix in the T4 condition. Nevertheless, the strength of the composite in the T4 state with the soft matrix can be pretty high because of reinforcing particles sharing a more considerable quotient of total load, which requires a more considerable accommodation strain around the particles; meanwhile, the strain discontinuity is not as severe as to cause debonding.

(6) They have a higher K1c, lower thermal expansion, and a better ability to accommodate a considerable mismatch strain at the interfaces, making BN particles the best reinforcement over WC particles in strength and flexibility.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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