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To cite this article: P.O. Babalola *et al* 2019 *J. Phys.: Conf. Ser.* **1378** 042028

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Modification to Metal Matrix Composites Nomenclature

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Abstract.

Naming Metal matrix composite (MMC) is very crucial to both the developer and the end users. It is an indication of what the developer put together which goes a long way in assisting the end user in selecting from myriad of available MMCs. The existing nomenclature put forward by Aluminium Association identified the matrix, reinforcement, percentage composition and the form of reinforcement but left out the particle size of the reinforcement. The particle sizes have been found to have significant effect on the properties of MMC and should be included in the adopted naming system. This paper revised the existing standard from 'Matrix/reinforcement/volume%form' to 'Matrix/reinforcement/volume%form/size in microns or nano'.

Key words: MMC, nomenclature, particle sizes, reinforcement, mechanical properties

1. Introduction

Naming and identifying traditional materials; metal, plastic (polymer) and ceramics were pretty easy. However, the advent of composite materials which is the combination of at least two of the traditional materials came with its own challenge, naming the composite. Composites may be metal matrix composite (MMC), polymer matrix composite (MMC), ceramic matrix composite (CMC) and carbon-carbon composite (CCC) depending on the major constituent known as the matrix. Because more aluminium MMCs are synthesized more than all other metal matrix alloys, the Aluminium Association (AA) evolved a nomenclature for naming MMCs that has since been used by the American National Standards Institute. ANSI 35.5-1992 requires that Al-MMCs be designated as follows [1]:

Matrix/reinforcement/volume%form

For example, 6061/B/50f describes the AA-registered alloy 6061 reinforced with 50 volume per cent of boron fibre; 6092/SiC/17.5p is the AA-registered alloy 6092 reinforced with 17.5 volume percent of silicon carbide particles; and A356/C/7.5c is an AA-registered casting alloy with 7.5 volume percent of chopped graphite fibres. This designation system was used by many researchers [2-14]. However, the particle size of the reinforcement is not captured by the existing designation system. Unfortunately, results from researchers have consistently proved that particle size has considerable effect on the properties of the composite. For example, Tjong [15] and Law *et al.* [16] used nanoscale (10^{-9} m) particles in aluminium matrix and documented that even at low particle volume fractions, there were marginal increase in the mechanical strength of the composites. These are known as metal matrix nano-composites (MMNCs). Law *et al.* [16] also reported that an increase in particle



sizes (nanometer) reduces flow stress (τ_{flow}) and the degree of hardening (n). Zhang and Lou [17] studied the homogeneous scattering of ceramic particles in centrifugally cast SiCp/Al and SiCp/Fe functionally graded materials (FGMs) composites with electromagnetic mixing. Particle size from 180 to 550 μm were used in the work and it was recorded that fine particles have uniform distribution with the use of magnetic field than coarse particles. This shows that the particle size would affect the distribution and consequently the properties of the composite

Some researchers also examined the effect of particle sizes of reinforcement on the electrical properties of composites. Srivastava and Ojha [4] method of producing Al–SiCp composites was by spray forming route with variable particle flow rate, volume fraction and reinforcement size. They studied the electrical conductivity and microstructure of the produced composites. Their findings indicated a remarkable effect of particle size in electrical conductivity (See Figure 1).

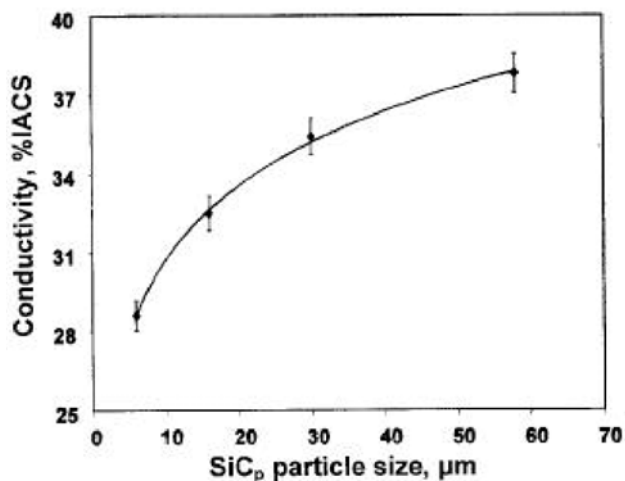


Figure 1: Electrical conductivity against particle size of AMC [4]

Hence additional information to the existing designation system by adding the size (in micron or nano-meter) of the particles is necessary. The revised designation system now becomes:

Matrix/reinforcement/volume%/form/size in microns or nano

2. Materials and Methods

2.1 Synthesizing the composites

Today, researchers have various options to synthesis MMCs such as squeeze casting, co-spray deposition, vacuum hot pressing, centrifugal casting, stir casting and so on. Stir casting method was used in this work. This is a liquid metallurgy route and details of the procedure is documented by Babalola et al [18&19].

2.2 Characterization of the composites

Mechanical tests were conducted on the produced composites. Detailed procedures for hardness tests was reported by Babalola et al [19]. Details for the tensile test was reported by Inegbenebor et al [20]. The results were analyzed using Excel, MATLAB and Artificial Neural Network software and mathematical models were generated for simulation purposes [19].

3.0 Results and discussion

3.1 Effect of Particle Sizes of Silicon Carbide on Modulus of AMCs

The average size of the particles of SiC has remarkable impart on the Modulus (N/mm^2) of AlSiC. Figure 2, Figure 3, Figure 4 and Figure 5 showed the effect on modulus when the reinforcement percentage weights were 2.5%, 5.0%, 7.5% and 10% respectively. It could be seen that the modulus of the composites (after the addition of SiC to Al) were higher than the monolithic Aluminium. Other observations and specific properties (Modulus) with modelling equation for each of the weight percentages are discussed below.

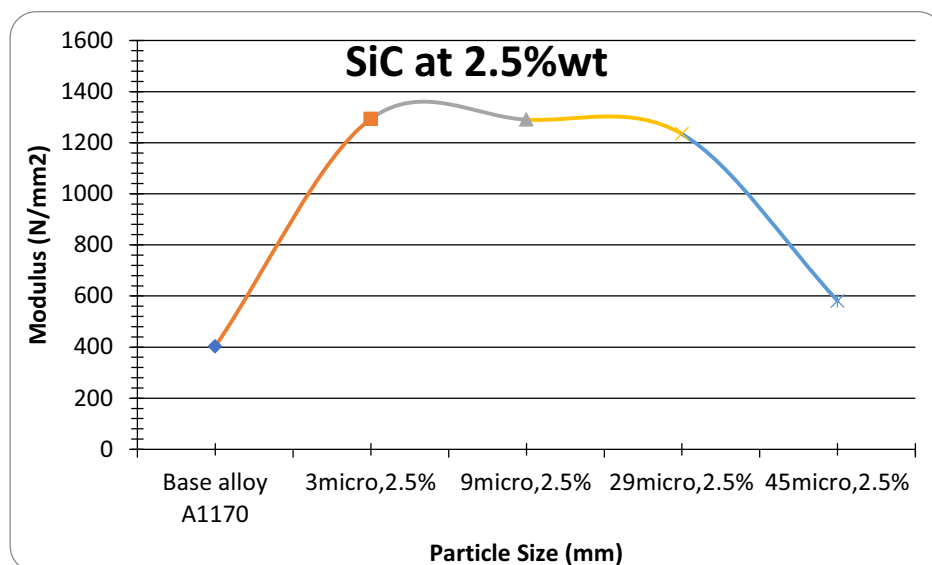


Figure 2: Modulus (N/mm^2) of Al/SiCp (2.5%wt) and particle size of SiC

When the silicon carbide content was restricted to 2.5% (Figure 2), a peak of 1293.428876N/mm^2 was recorded for $3\mu\text{m}$ grit size composite compared with that of the base metal of 402.413324N/mm^2 . However, at a higher size of $45\mu\text{m}$, there was a reduction on the modulus (580.916218N/mm^2) though it was still higher than that of the base Aluminium matrix. The modelling equation was a quadratic function [21]:

$$E = -1.6602m^2 + 70.061m + 736.63$$

(1)

where $E = \text{Modulus (N/mm}^2)$

$m = \text{SiC particle size}$

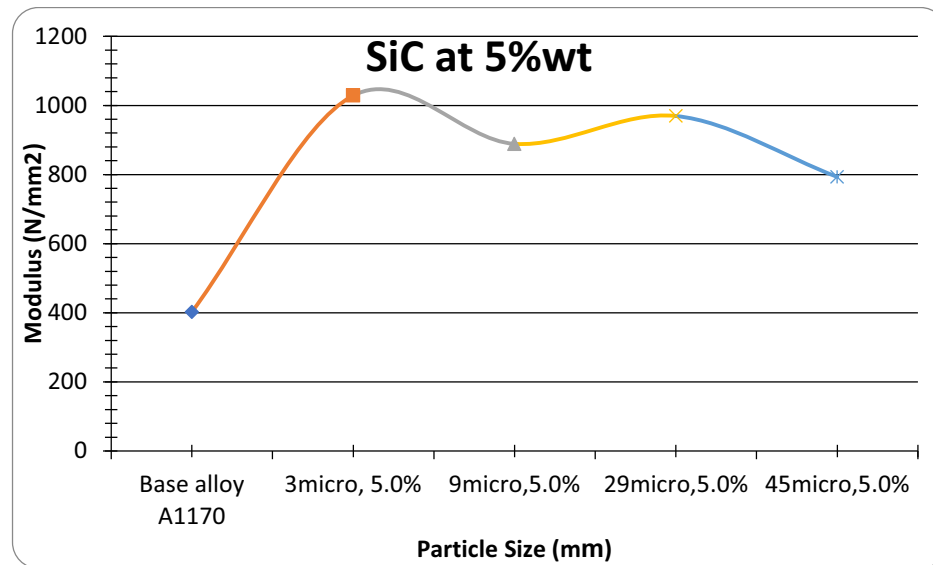


Figure 3: Modulus (N/mm²) of Al/SiCp (5.0%wt) and particle size of SiC

For 5.0 percentage weight of SiC, it could be seen that the modulus of the composites is higher than the monolithic Aluminium (Figure 3). A peak of 1028.563265N/mm² was recorded for 3µm grit size composite compared with that of the base metal of 402.413324N/mm². However, at bigger particle sizes of 9µ, 29µ and 45µm, there were reduction on the modulus (888.772108N/mm², 969.405182² and 793.2229175N/mm²) though they are still higher than that of the base Aluminium matrix. The modelling equation was a quadratic function:

$$E = -0.70001m^2 + 34.179m + 642.45 \quad (2)$$

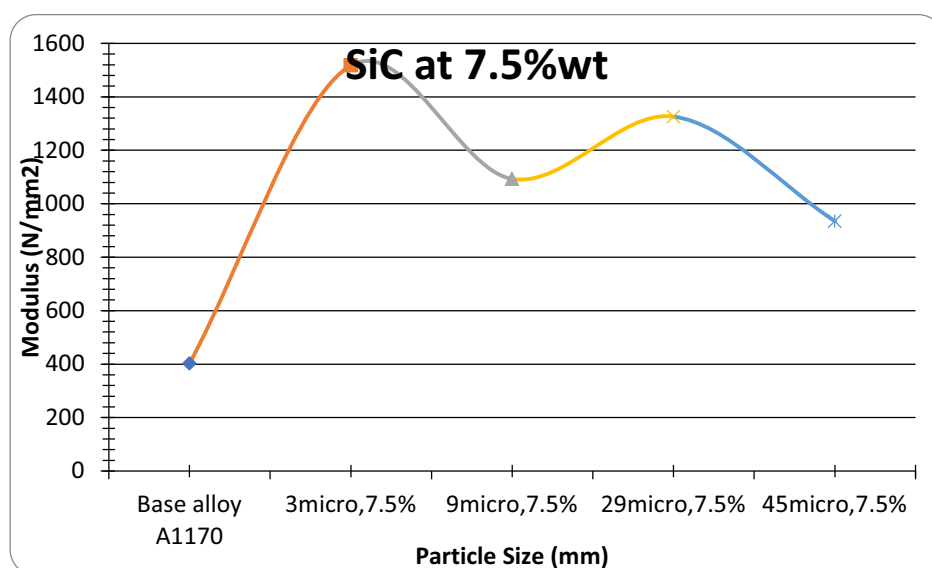
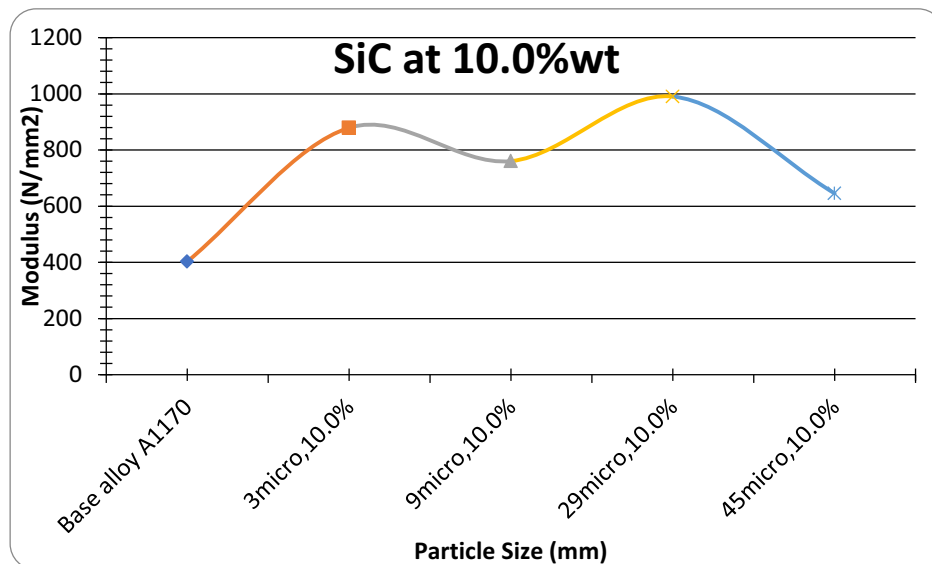


Figure 4: Modulus (N/mm²) of Al/SiCp (7.5%wt) and particle size of SiC

For 7.5 percentage weight of SiC, it could be seen that the modulus of the composites was higher than the monolithic Aluminium (Figure 4). A peak of 1517.59211N/mm² was recorded for 3 μ m grit size composite compared with that of the base metal of 402.413324N/mm². However, at bigger particle sizes of 9 μ , 29 μ and 45 μ m, there were reduction on the modulus (1092.8752N/mm², 1326.21316² and 935.028496N/mm²) though they are still higher than that of the base Aluminium matrix. The modelling equation was a quadratic function:

$$E = -1.1501m^2 + 53.806m + 809.33 \quad (3)$$

Figure 5: Modulus (N/mm²) of Al/SiCp (10.0%wt) and particle size of SiC

Lastly, at 10.0 percentage weight of SiC, it could be seen that the modulus of the composites was higher than the monolithic Aluminium (See Figure 5). A peak of 990.415216N/mm² was recorded for 29 μ m grit size composite compared with that of the base metal of 402.413324N/mm². However, at a higher size of 45 μ m, the least value for the composite (645.46291N/mm²) was recorded, though it was still higher than that of the base Aluminium matrix. The modelling equation was a quadratic function:

$$E = -0.84115m^2 + 39.97m + 545.32 \quad (4)$$

3.2 Effect of Particle Sizes of Silicon Carbide on Hardness of AMCs

Furthermore, the influence of particle sizes when the composition of silicon carbide is constant was investigated. It was observed that increase in particle size led to increase in hardness [18].

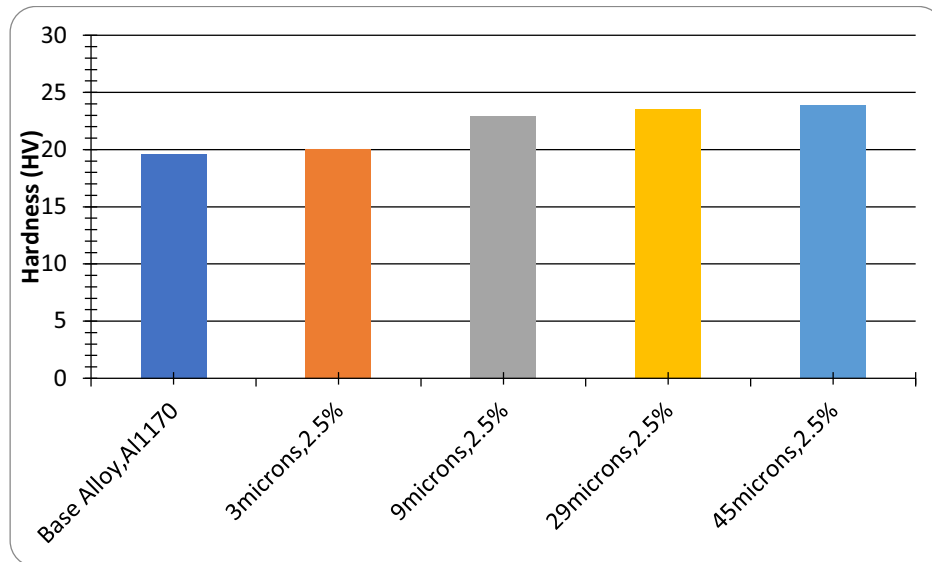


Figure 6: The Effect of Particle Size of SiC Particulates on the Hardness of Al/SiCp (2.5%wt)

When the percentage weight of the SiC particle was kept constant (2.5%wt) while increasing the particle sizes from 3μ to 45μ , the hardness of the composites was found to be increasing with size. The composites generally have higher hardness values than the pure Aluminium (Figure 6). The modelling equation was a linear function:

$$H = 0.0843v + 20.64, R^2 = 0.7143 \quad (5)$$

where H = Hardness

v = SiC particle size in microns

R^2 = Coefficient of determination

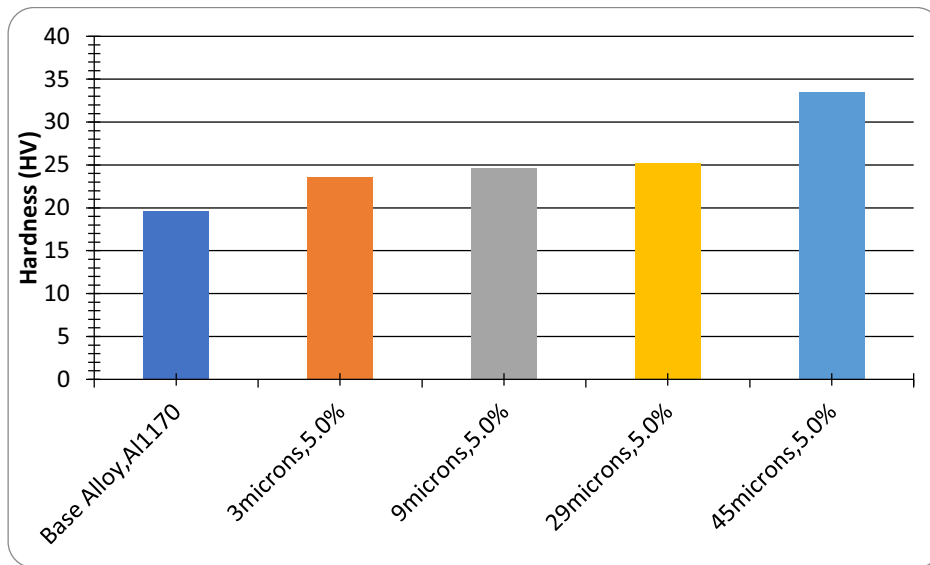


Figure 7: The Effect of Particle Size of SiC Particulates on the Hardness of Al/SiCp (5%wt)

When the percentage weight of the SiC particle was kept constant (5%wt) while increasing the particle sizes from 3μ to 45μ , the hardness of the composites was found to be increasing with size, higher than that of the Aluminium matrix (Figure 7). The modelling equation was a linear function:

$$H = 0.239v + 21.19, \quad R^2 = 0.8249 \quad (6)$$

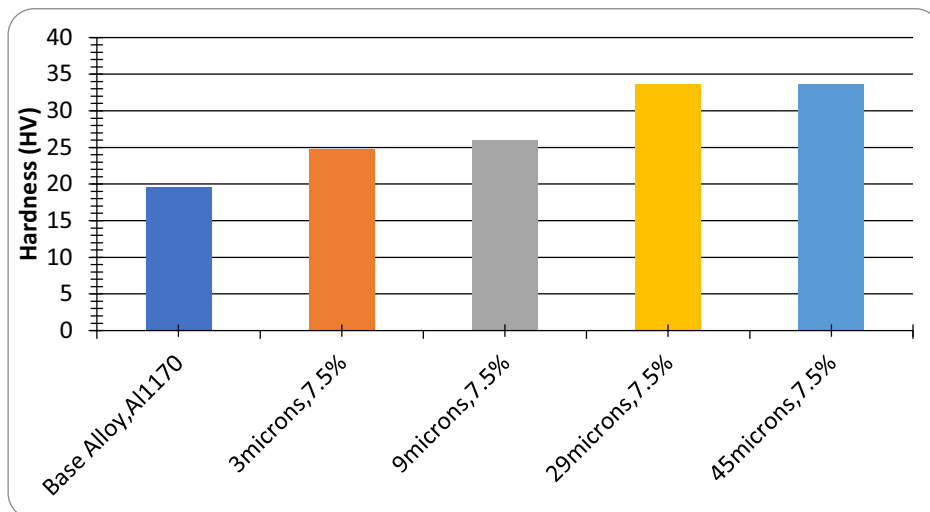


Figure 8: The Effect of Particle Size of SiC Particulates on the Hardness of Al/SiCp (7.5%wt)

When the percentage weight of the SiC particle was kept constant (7.5%wt) while increasing the particle sizes from 3 μ to 45 μ m, the hardness of the composites was also found to be increasing with size, higher than that of the Aluminium matrix (Figure 8). The modelling equation was a linear function:

$$H = 0.2914v + 22.528, \quad R^2 = 0.849 \quad (7)$$

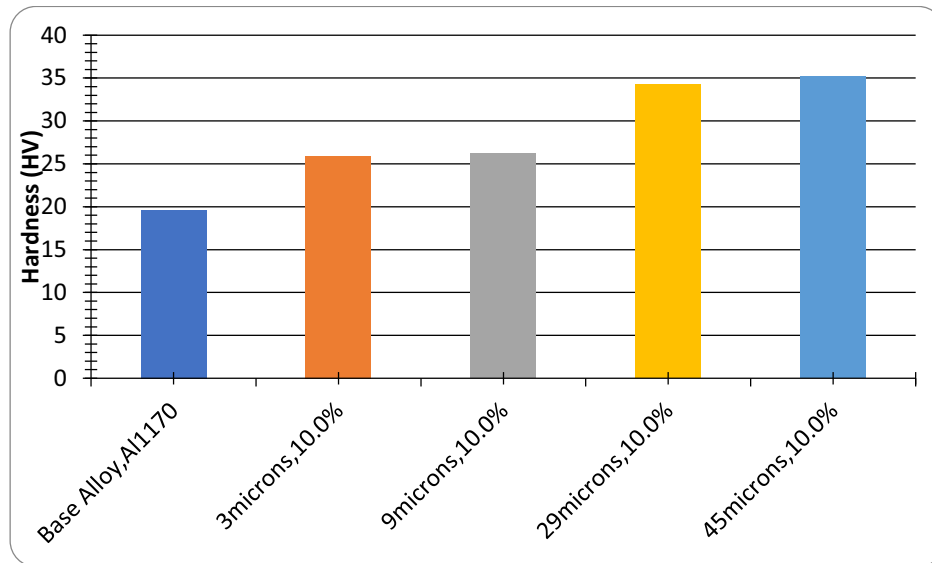


Fig. 9. Effect of SiC Particulate Size on the Hardness of Al/SiCp (10%wt)

Lastly, SiC particle was kept constant (10%wt) while increasing the particle sizes from 3 μ to 45 μ m, the hardness of the composites were also found to be increasing with size and higher than that of the Aluminium matrix (Figure 9) just like the previous observation. The modelling equation was also a linear function:

$$H = 0.3135v + 22.838, \quad R^2 = 0.8596 \quad (8)$$

4.0 Conclusions

The following inferences were arrived at from the results generated in this work:

- i. The particle sizes of the reinforcement have a significant impact on the mechanical properties (tensile, hardness) of the resultant composites.
- ii. It is strongly advocated that relevant standard organizations (e.g. ANSI), regulatory institutions and researchers should specify the size of the reinforcement particle when designating metal matrix composites.

iii. Old designating method (Matrix/reinforcement/volume%form) is strongly advised to be replaced by the new suggested designating system (Matrix/reinforcement/volume%form/size in microns). An example is Al/SiC/10p/3mm which describes aluminium matrix reinforced with 10 volume percent of silicon carbide particles, the average size of SiC particles is 3 micrometres.

Funding: The authors acknowledge Covenant University Centre for Research, Innovation and Discoveries (CUCRID) Ota, Nigeria for the sponsorship and provision of research facilities for this work.

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