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Effective Elastic Properties of an Al–SiC Particulate Composite Using FEM-Based RVE in SimScale

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ABSTRACT

This paper presents a finite element–based homogenization study to evaluate the effective elastic properties of an aluminum–silicon carbide (Al–SiC) particulate composite. A three-dimensional representative volume element (RVE) containing randomly distributed spherical SiC particles is analyzed using the SimScale platform. Under uniaxial loading conditions, the composite exhibits an effective Young's modulus of 74 GPa, with an average axial stress of 73.16 MPa corresponding to an average strain of 9.88×10^{-4}. The resulting elastic properties, stress, strain, and displacement fields are extracted and discussed in detail. Furthermore, the numerical results are compared with predictions obtained from the Tanaka micromechanical model, showing good agreement and confirming the validity of the proposed FEM-based RVE approach.

الخواص المرنة الفعّالة لمركب جسيمي من الألومنيوم–كربيد السيليكون (Al–SiC) باستخدام الحجم العنصري التمثيلي المعتمد على طريقة العناصر المحددة (FEM–Based RVE) في برنامج SimScale .

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الـمُخلص

تقدم هذه الورقة البحثية دراسة تجانس قائمة على طريقة العناصر المحدودة لتقييم الخصائص المرنة الفعالة لمركب جسيمات الألومنيوم–كربيد السيليكون .(Al–SiC) تم تحليل عنصر حجمي تمثيلي ثلاثي الأبعاد (RVE) يحتوي على جسيمات كروية من كربيد السيليكون موزعة عشوائيًا باستخدام منصة SimScale في ظل ظروف التحميل أحادي المحور، أظهر المركب معامل يونغ فعالًا قدره 74 جيجا باسكال، مع إجهاد محوري متوسط قدره 73.16 ميجا باسكال، ما يعادل انفعالًا متوسطًا قدره 9.88×10^{-4}. تم استخراج الخصائص المرنة الناتجة ، والإجهاد ، والانفعال , والإزاحة، ومناقشتها بالتفصيل. علاوة على ذلك، تمت مقارنة النتائج العددية مع التنبؤات المستمدة من نموذج تاناكا الميكانيكي الدقيق، مما أظهر توافقًا جيدًا وأكد صحة منهج RVE المقترح القائم على طريقة العناصر المحدودة.

الكلمات المفتاحية : العنصر الحجمي التمثيلي(RVE) ، طريقة العناصر المحددة(FEM) ، SimScale(برنامج محاكاة)، معامل يونغ (معامل المرونة الطولي).

1 Introduction

Particle-reinforced aluminum matrix composites have attracted significant attention due to their high stiffness-to-weight ratio and enhanced mechanical performance. Finite element homogenization based on representative volume elements (RVEs) is a powerful tool for predicting effective elastic properties while explicitly accounting for microstructural features such as particle size, distribution, and volume fraction[1,2].

1.1 Material Properties

The matrix material used in this study is Aluminum 6061, while silicon carbide (SiC) is employed as the reinforcing phase. The materials are assumed to be linear elastic and isotropic.

Aluminum 6061: Young’s modulus = 70GPa, Poisson’s ratio = 0.3.

Silicon Carbide (SiC): Young’s modulus = 410 GPa, Poisson’s ratio = 0.17.

2 RVE Geometry And Material Description

The composite material consists of an aluminum matrix reinforced with spherical silicon carbide (SiC) particles. The RVE is modeled as a cubic domain with a total volume of 1 mm³. A total of 191 spherical particles with a diameter of **100** µm are randomly distributed within the matrix, resulting in an approximate reinforcement volume fraction of 10%.

The particle diameter was determined by equating the total volume of the spherical particles to 10% of the RVE volume according to:

$$V_f = \frac{N.\frac{4}{3}\pi r3}{VRVE} \quad (1)$$

Where V_f is the reinforcement volume fraction, N is the number of particles, r is the particle radius, and VRVE is the RVE volume. Figure 1 shows the random spatial distribution of SiC particles within the aluminum matrix.

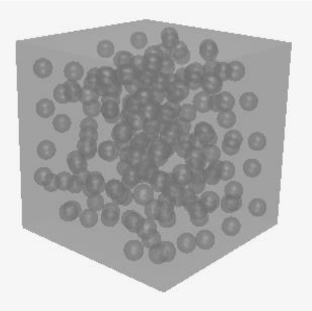


Fig.1: es with the aluminum matrix

3 Numerical Model And Boundary Conditions

A linear static structural analysis is carried out using the SimScale cloud-based finite element platform. Perfect bonding between the matrix and reinforcement particles is assumed. One face of the RVE is fully constrained, while a prescribed displacement is applied to the opposite face in the Z-direction to simulate uniaxial tensile loading. All materials were assumed to behave as linear elastic.Figure 2: Presents the displacement field in the loading direction, confirming a smooth and uniform deformation consistent with linear elastic behavior.

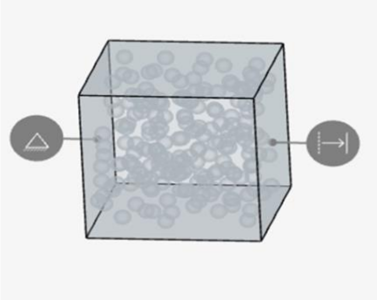


Fig.2: Displacement field

4 Results And Discussion

The averaged stress–strain response of the RVE is used to evaluate the effective elastic properties of the composite. Figure 3 illustrates the effective Young's modulus obtained from the slope of the stress–strain curve is 74 GPa. The average Cauchy stress in the Z-direction is 73.16 MPa, corresponding to an average axial strain of 9.88×10^{-4}.

Figure 4 illustrates the stress distribution within the RVE, showing stress concentration around the SiC particles due to the stiffness mismatch between the matrix and reinforcement.

Figures 5 and 6 illustrate the transverse strains of -3.008×10^{-4} in the X-direction and -2.991×10^{-4} in the Y-direction, resulting in an effective Poisson's ratio of approximately 0.304.

Figure 7 illustrates the total strain distribution in the Z-direction, showing a nearly uniform axial strain within the aluminum matrix with localized variations around the SiC particles due to stiffness mismatch.

Figure 8 illustrates the displacement field in the Z-direction. The results indicate a maximum displacement of 1.36 µm, an average displacement of 0.476 µm, and a minimum value of zero at the constrained surface, as expected.

Table 1: Effective elastic properties of the Al–SiC composite obtained from FEM.

Parameter	Value
Effective Young's modulus (GPa)	**74**
Average stress in Z (MPa)	**73.16**
Average axial strain (Z)	**9.88×10^{-4}**
Poisson's ratio	**0.304**

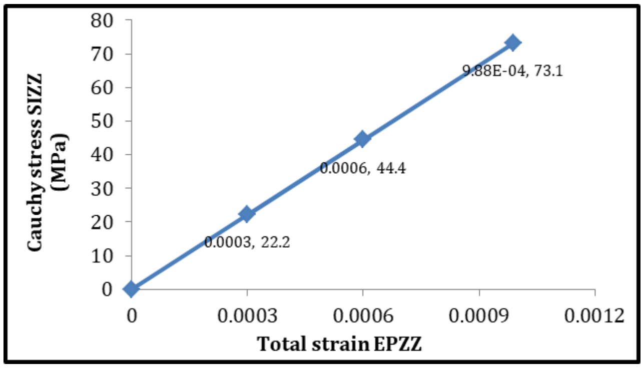


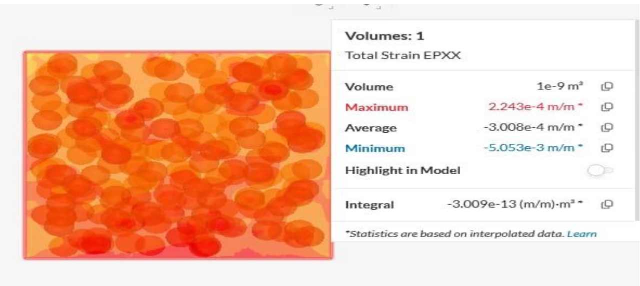
Fig.3: Young's modulus with Al6061+sic


Volumes: 1
Cauchy Stress SIZZ

Volume	1e-9 m³
Maximum	6.786e+8 Pa *
Average	7.316e+7 Pa *
Minimum	-2.886e+7 Pa *
Highlight in Model	
Integral	7.319e-2 (Pa)·m³ *

*Statistics are based on interpolated data. Learn

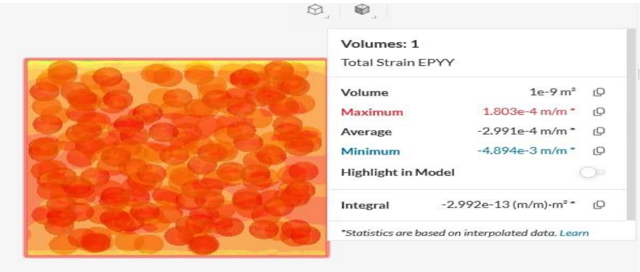
Fig.4 : Stress distribution


Volumes: 1
Total Strain EPXX

Volume	1e-9 m³
Maximum	2.243e-4 m/m *
Average	-3.008e-4 m/m *
Minimum	-5.053e-3 m/m *
Highlight in Model	
Integral	-3.009e-13 (m/m)·m³ *

*Statistics are based on interpolated data. Learn

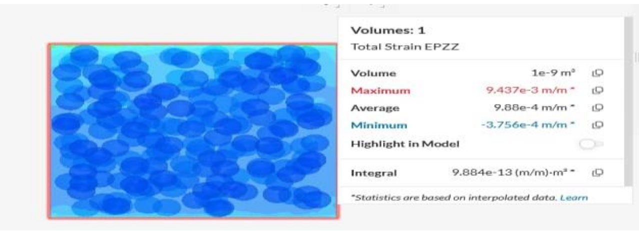
Fig.5 : Total strain EPXX with Al6061+ sic


Volumes: 1
Total Strain EPYY

Volume	1e-9 m³
Maximum	1.803e-4 m/m *
Average	-2.991e-4 m/m *
Minimum	-4.894e-3 m/m *
Highlight in Model	
Integral	-2.992e-13 (m/m)·m³ *

*Statistics are based on interpolated data. Learn

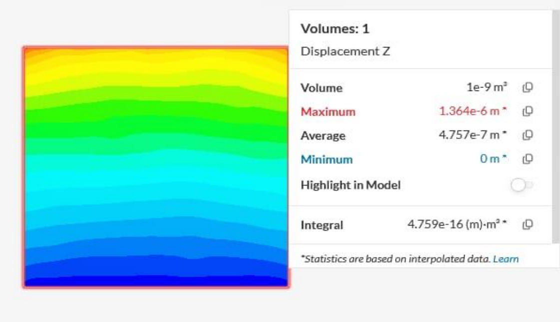
Fig.6 : Total strain EPYY with Al6061+sic


Volumes: 1
Total Strain EPZZ

Volume	1e-9 m³
Maximum	9.437e-3 m/m *
Average	9.88e-4 m/m *
Minimum	-3.756e-4 m/m *
Highlight in Model	
Integral	9.884e-13 (m/m)·m³ *

*Statistics are based on interpolated data. Learn

Fig.7: Total strain EPZZ with Al6061+ sic


Volumes: 1
Displacement Z

Volume	1e-9 m³
Maximum	1.364e-6 m *
Average	4.757e-7 m *
Minimum	0 m *
Highlight in Model	
Integral	4.759e-16 (m)·m³ *

*Statistics are based on interpolated data. Learn

Fig.8 : Displacement Z with Al6061+sic

5 Theoretical Comparison Using The Tanaka Model

The effective Young's modulus of the composite is also estimated using the Tanaka micromechanical model for particle-reinforced materials[3].The model is expressed as:

$$E_{eff} = E_m \times [(1 + A\cdot V_f) /(1 - B\cdot V_f)] \tag{2}$$

where E_{eff} is the effective Young's modulus of the composite, E_m is the Young's modulus of the matrix material, V_f is the particle volume fraction, and A and B are constants that depend on the elastic properties of the matrix and reinforcement. For a reinforcement volume fraction of approximately 10%, the Tanaka model predicts an effective modulus close to the FEM result of 74 GPa, demonstrating good agreement between numerical and analytical approaches. While the Tanaka model provides an analytical estimate based on average field assumptions, the FEM-based RVE approach captures local stress–strain heterogeneity arising from particle–matrix interactions [4,5].

6 Conclusions

A finite element–based RVE approach has been successfully applied to predict the effective elastic properties of an Al–SiC particulate composite. The results obtained using SimScale show strong agreement with the Tanaka theoretical model and handbook values validating the numerical methodology. The presented framework can be extended to study the influence of particle size, volume fraction, and distribution on composite behavior.

References

[1] Peng, Y., Zhao, H., Ye, J., Yuan, M., Tian, L., Li, Z., Wang, Z., & Chen, J. (2022). Multiscale 3D finite element

analysis of aluminum matrix composites with nano and micro hybrid inclusions. *Composite Structures*, 288, 115425.

[2] Schindler, S., Mergheim, J., Zimmermann, M., Aurich, J. C., & Steinmann, P. (2017). Numerical homogenization of elastic and thermal material properties for metal matrix composites (MMC). *Continuum Mechanics and Thermodynamics*, 29(1), 51–75.

[3] Tanaka, K., Mori, T., & Wakashima, K. (1973). The effect of particle size on the elastic moduli of particle-reinforced composites. *Acta Metallurgica*, 21(5), 567–576.

[4] Callister, W. D. (2014). *Materials Science and Engineering: An Introduction* (9th ed.). Wiley.

[5] Chawla, N. (2012). *Metal Matrix Composites* (2nd ed.). Springer.