UDK 669.715:539.383 ISSN 1580-2949
Original scientific article/Izvirni znanstveni članek MTAEC9, 57(2)201(2023)

DYNAMIC COMPRESSIVE PROPERTIES OF ALUMINIUM-MATRIX COMPOSITES REINFORCED WITH SiC PARTICLES

DINAMIČNE TLAČNE MEHANSKE LASTNOSTI ALUMINIJEVIH KOMPOZITOV OJAČANIH Z DELCI SiC

Dianyu Fu[1], Yunhan Ling[1*], Peng Jiang[1], Yong Sun[1], Chao Yuan[1], Xiaoming Du[2]

[1]Beijing Research Institute of Mechanical & Electrical Technology Co., Ltd, Beijing 100083, China
[2]School of Materials Science and Engineering, Shenyang Ligong University, Shenyang 110159, China

Prejem rokopisa – received: 2022-07-27; sprejem za objavo – accepted for publication: 2023-03-01

doi:10.17222/mit.2022.580

The aluminium-matrix composites (AMCs) consisted of (5, 10 and 15) *x*/% SiC particles (SiCp) in an aluminium alloy 7055 matrix. Specimens were taken from hot-press sintering. High-strain-rate tests were performed using the split-Hopkinson pressure bar (SHPB) method. The microstructures were observed with a scanning electron microscope (SEM) to understand the damage mechanisms of the SiCp/7055 Al composites at high strain rate. The SHPB test results show that the SiCp-reinforced composites are more sensitive to strain rate than the unreinforced material. The strain-rate sensitivity of the flow stress of these composites increases substantially with the increase of the strain rate. The flow stress of SiCp/7055Al composites with 10 *x*/% and 15 *x*/% SiCp at 3000 s^{-1} first increases and then decreases with the increase of the plastic strains, which was caused by the heat generated during adiabatic compression. Microstructure-characterization results show that SiCp cracking and SiCp/7055Al interface debonding are the main damage mechanisms of the composites. The SiCp volume fraction and strain rate affect the damage of composites during the dynamic compressive deformation of the SiCp /7055Al composites.

Keywords: Al/SiCp composite; dynamic compressive test; strain rate; damage

Kompoziti s kovinsko osnovo iz aluminijeve zlitine vrste Al7055 (AMCs) vsebujejo običajno (5, 10 ali 15) *x*/ % silicij karbidnih delcev (SiCp). Avtorji so izdelali vzorce (preizkušance) te vrste kompozitov s postopkom vročega sintranja pod tlakom. Na izdelanih preizkušancih so izvedli preizkuse hitre tlačne deformacije s pomočjo Hopkinsove cepilno tlačne metode (SHPB; split-Hopkinson pressure bar method). Za razumevanje mehanizma nastalih poškodb na preizkušancih Al7055/SiCp zaradi velikih hitrosti deformacije, so opazovali njihovo mikrostrukturo s pomočjo vrstičnega elektronskega mikroskopa (SEM). Rezultati testov SHPB so pokazali, da so izbrani kompoziti ojačani z SiCp bolj občutljivi na hitrost deformacije kot neojačan material oz. čista zlitina Al7055 brez delcev SiC. Ugotavili so, da občutljivost meje tečenja kompozitov narašča močno z naraščanjem hitrosti deformacije. Napetost tečenja kompozitov Al7055/SiCp z (10 in 15) *x*/% SiCp pri 3000 s^{-1} najprej narašča in nato pada z naraščanjem plastične deformacije, kar je posledica tvorbe toplote med adiabatno tlačno deformacijo. Mikrostrukturne preiskave so pokazale, da se SiCp lomijo oziroma pokajo in da je glavni mehanizem poškodb kompozitov cepljenje na mejah med SiCp in kovinsko osnovo iz Al7055. Volumski delež SiCp in hitrost deformacije močno vplivata na poškodbe in porušitev kompozitov med dinamično tlačno deformacijo kompozitov vrste Al7055/SiCp.

Ključne besede: kompoziti Al/SiCp; dinamični tlačni test; hitrost deformacije; poškodba in porušitev

1 INTRODUCTION

Aluminium-matrix composites (AMCs) reinforced with SiCp possess excellent properties, including high specific strength and specific stiffness, high plastic flow strength, creep resistance, low thermal expansion coefficient, satisfactory wear resistance, good corrosion resistance and isotropy. These properties make particle-reinforced AMCs strong candidates for use within a wide range of applications, such as aviation and aerospace, electronic communication, automobile, military and other fields.[1–4]

In many engineering applications, AMCs will inevitably be subjected to dynamic loadings. Materials and structures used in aerospace, high-speed railway, the armours of missile vehicles and other fields often face a complex service environment under transient impact loadings. Further, large dynamic deformations are developed during several of the manufacturing processes applied to these materials.[5] The macroscopic mechanical properties and microstructure of the material under high-strain-rate loading will change significantly compared with that under quasi-static loading.[6] Therefore, it is of great scientific and engineering significance to study the mechanical properties and damage evolution process of AMCs under high strain rate.

In recent years, a great deal of research on the dynamic compressive behaviour of Al/SiCp composites has been carried out. Li et al. studied SiCp/Al composites' compression properties at a strain rate range of 10^{-5}–10^{5}/s and dynamic shearing deformations by SHPB.[7] Kalambur and Hall indicated the dynamic compressive behaviour of 25 *x*/% SiCp/2024 Al composites.[8]

*Corresponding author's e-mail:
424212121@qq.com (Yunhan Ling)

Cao et al. believed that SiCp/Al composites with large particles were more prone to particle breakage and interface failure than composites with small particles during dynamic compressive testing.[9]

More recently, Lee et al. concluded that three damage modes existed in the dynamic deformation process of SiCp/Al composites with a high volume fraction, i.e., matrix softening, particle breakage, and interface failure by the SHPB.[10–12] They believed that particle breakage and interface failure were the major damage modes that severely affected the dynamic compressive strength of the composites. However, the relationships between the particle volume fraction and the particle damage are not known. The particle damage affects the dynamic compressive properties of SiCp/Al composites by weakening the strengthening effect of the reinforcement. Moreover, some researchers believe that the particle size of the reinforcement has a significant impact on the damage and fracture mechanisms of AMCs. Lloyd concluded that small silicon carbide particles with 7.5 µm diameter gave significantly higher plastic work hardening than large particles with a 16-µm diameter.[13] Kiety et al. found that the rupture toughness of particle-reinforced metal-matrix composites had a peak value, then decreased significantly when the particle size increase.[14] Up to now, relatively limited investigations have been made to address the damage and fracture mechanisms of particles with different sizes in particle-reinforced metal-matrix composites. Therefore, it is necessary to investigate the influence of particle volume fraction and size on the damage of particles to reveal the dynamic damage mechanism of composites more accurately.

The objective of this research is to investigate the influence of particle volume fraction on the dynamic compressive behaviour and damage mechanism of SiCp/7055Al composites at various strain rates. The dynamic uniaxial compression tests were performed on the hot-pressed sintered SiCp/7055Al composites with different volume fractions of SiC particles, while the stress-strain data were obtained with a SPHB. The effects of strain rate, strain hardening and particle volume on the flow stress were analysed. The microstructures were characterized by SEM. The corresponding deformation and damage mechanisms were also discussed.

2 EXPERIMENTAL PART

Commercially available, Al powder (purity 99.99 %) with an average particle size of 10 µm, analytical purity Mg, Cu and Zn powders (purity 99.80 %), which were mixed according to a certain weight percentage (Al-7.8%Zn-2.0 %Mg-2.6%Cu, 7055 Al), were used as the matrix materials. This resulted in good mechanical prosperities, good oxidation and corrosion resistance, making 7055 Al a strong candidate for use within aerospace applications. The α-SiC particle was chosen as the reinforcement phase. The mean particle size of SiCp was 15 µm. The volume fractions of SiC particles in the AMCs were (5, 10 and 15) *x*/%, respectively. To obtain SiCp/7055Al mixed powders, Al, Zn, Mg, Cu and SiC powders were blended in an agate container for 12 h. Zirconia balls with a diameter of 5 mm were used. The mass ratio of the ball-to-powder was 5:1. The blended powder was containerized in a heat-resisting steel die (50 mm in diameter, 200 mm in height) and then compacted. The compacted composite billets were sintered at 620 °C in a vacuum of 1 Pa for a period of 2h under a pressure of 30 MPa by hot-press sintering. SiCp/7055Al composites with different volume fractions of SiC particles were developed. For comparison, a 7055 Al specimen without SiCp was also fabricated under the same conditions. After sintering, all the specimens received 2 h of solution heat treatment at 470°C, quenching in cold water, and 16 h artificial aging at 160 °C.

Conventional SHPB equipment with 20-mm diameter bars was used for the dynamic compression tests at strain rates ranging from 1500 s^{-1} to 3000 s^{-1}.[15–17] The specimens that were machined in cylindrical shape with 5 mm in length and 7 mm in diameter by electro-discharge machining were used for dynamic compression tests. The surfaces of the cylindrical specimens were finely ground and made as flat and as parallel as possible. Scanning electron microscopy (S-3400N) was used to study the microstructure of the composites.

3 RESULTS AND DISCUSSION

3.1 Stress-strain curves

Figure 1 illustrates that the stress-strain curves of the (0, 5, 10 and 15) *x*/% SiCp/7055Al composites under various strain rates. As can be seen from Figure 1a, when the strain rate of the Al matrix alloy is 1500 s^{-1} and 3000 s^{-1}, the stress-strain curves are almost identical, indicating that the alloy shows no obvious strain-rate sensitivity in this strain-rate range. However, it is evident that the strain rate has a significant effect on the overall strength and strain-hardening properties of the SiCp/7055Al composites from **Figures 1b**, **1c** and **1d**. The alloy also shows obvious strain hardening properties during the high-strain-rate compression deformation. With the increase of the strain rate the effective plastic strain increases; SiCp/7055Al composites have larger elongation at same strain rates compared to the Al matrix alloy. In addition, it can be also found from **Figure 1c** and **1d** that when the strain rate reaches 3000 s^{-1}, the flow stress of the SiCp/7055Al composites with (10 and 15) *x*/% SiCp first increases and then decreases with the increase of the plastic strains. The decrease in the flow stress might be caused by the heat generated during adiabatic compression, which makes the matrix material softened or melted and results in the decrease of flow stress at high strain rate. Moreover, **Figure 2** shows a variation of flow stress of SiCp/7055Al with (5, 10 and 15) *x*/% particles at plastic strain of 3 % at various strain rates. It

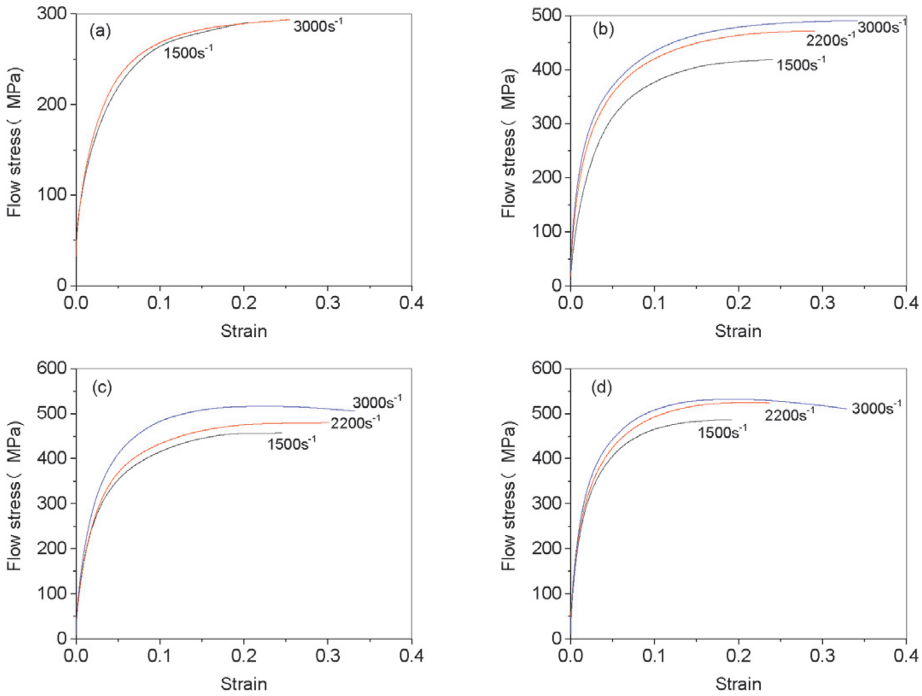

Figure 1: Stress-strain curves for SiCp/7055Al composites at various strain rates: a) Al matrix, b) 5 *x*/%, c) 10 *x*/%, d) 15 *x*/%

can be found that the flow stress of SiCp/7055Al significantly increases with an increasing volume fraction of reinforcement.

The dynamic compression under the condition of high strain rate at room temperature is equivalent to an adiabatic compression process. A lot of heat will be generated in the material and there is not enough time to diffuse outwards. This will cause the temperature of the material to increase with the increase of the strain rate and strain. The temperature rise might cause a material-softening effect. Tan et al. have also found that a larger elongation at high strain rates and increase–decrease trend with strain rate for flow stress in dynamic compression tests for SiCp/2024Al composite materials.[18,19] The temperature rise ΔT cab be given as follows[20]

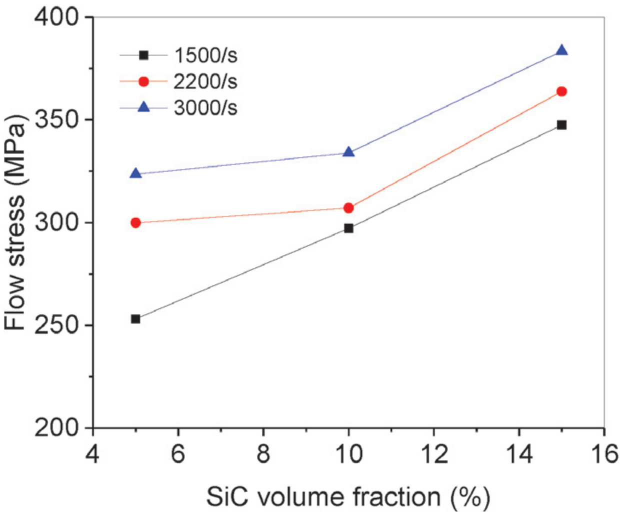

Figure 2: Variation of flow stress at 3 % plastic strains with reinforcement volume fractions of (5, 10 and 15) *x*/% SiCp/7055Al composites

$$\Delta T = \frac{\alpha}{\rho_c C_v} \int_0^{\varepsilon} \sigma \mathrm{d}\varepsilon \qquad (1)$$

where α is the fraction of the plastic work converted to heat. Generally, 0.9 is taken in the high strain rate compression deformation test of aluminium alloy;[21] σ and ε are the true stress and plastic strain, respectively; ρ is the density and C_v is the specific heat. The stress and strain in **Figure 1** were used to estimate the temperature rise. The density of THE 7055Al aluminium alloy and THE SiC particles are 2.85 g/cm^3 and 3.2 g/cm^3, respectively. The density of the SiCp/7055Al composite is obtained from $\rho_c = \rho_p V_p + \rho_M (1 - V_p)$, where ρ_p and ρ_M are the density of the reinforced particle and the matrix material, respectively. The specific heats of the aluminium alloy and the SiC particles are about 886 J/(kg·K)[22] and 399 J/(kg·K),[23] respectively.

The specific heat of the SiCp/7055Al composites can be determined by a mixing law.[24] The temperature rise estimated using Equation (1) was shown in **Figure 3**. It was found that the temperature rise during dynamic compression is in the range 30–62 K for SiCp/7055Al composites and increases with the increase of the strain rate. It is important to note that the maximum temperature rise in dynamic compression of the SiCp/7055Al composite at a high strain rate of 3000 s^{-1} is 54.2,58.6 and 61.5 K for 5 *x*/%, 10 *x*/% and 15 *x*/% SiCp, respectively. This can cause the reduced flow stress owing to the thermal softening of the Al matrix. Therefore, the effect of thermal softening on SiCp/7055Al composite cannot be negligible. Generally, the transient heat generated by dy-

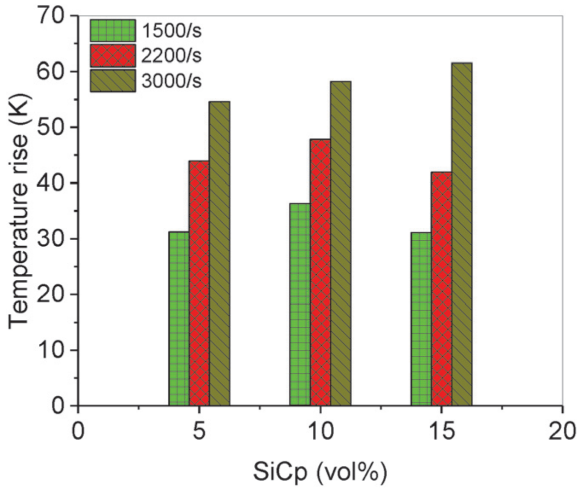

Figure 3: Temperature rise of SiCp/7055Al composites at different strain rates

namic compression at high strain rates softens the matrix alloys, resulting in a decrease in the load-carrying capacity of the matrix. This phenomenon was found and confirmed by most researchers.[18,19,25] According to the relevant estimation method, the heat can increase the matrix temperature by about 60 °C. If the adiabatic heating effect is investigated by static compression at 60 °C, there will be a significant difference between the microstructure and that under dynamic compression conditions. Because this will lose the strain-rate hardening effect. Tan et al. have investigated the effect of thermal softening on the strength of SiCp-reinforced 2024Al matrix composites.[19] They found that thermal softening made the flow stress decrease at high strain rates. Sun et al. found that the maximum temperature rise in dynamic compression of the Al/SiCp composite is 18.8 K and believed that the effects of adiabatic heating on the thermal softening of Al/SiCp composites can be negligible.[25] Lee et al. found that a part of the Al matrix without SiCp cracking or SiCp/Al interfacial debonding was easily melted by the temperature rise above the melting temperature of the A356 Al alloy.[10]

3.2 Effect of strain hardening and strain-rate sensitivity

Figure 4 shows the variation of the flow stress for given plastic strains with different strain rates for (5, 10 and 15) *x*/% SiCp/7055Al composites. It can be found from Figure 4 that the strain rate dominates the increasing flow stress compared with the strain hardening, and the flow stress increases substantially with the increasing of the strain rate. The strain hardening of aluminium-matrix composites with three SiCp contents shows the same trend, i.e., the increasing trend of flow stress by strain hardening becomes smaller with the increase of strain at the same strain rate. At strain from 3 % to 6 %, the flow stress increases from 253 MPa to 330 MPa at 1500 s^{-1} and increases from 323 MPa to 385 MPa at 3000 s^{-1}. The strain hardening has a larger influence on the flow stress at 1500 s^{-1} than that at 2200 and 3000 s^{-1} for 15 *x*/% SiCp/7055Al. For 10 and 15 *x*/% SiCp/7055Al composites, the flow stress also has a similar trend. This is because the heat generated by adiabatic compression is much greater at 3000 s^{-1} than at 1500 s^{-1}, which results in a softened matrix at 3000 s^{-1}. Moreover, the increasing of the flow stress by strain-rate hardening from 1500 s^{-1} to 3000 s^{-1} is much higher than that by strain hardening from 3 % to 6 % strain, which shows that the effect of strain-rate hardening is stronger than strain hardening. Tan et al. obtained similar results for 40 *x*/% SiCp/2024Al-matrix composites.[19]

In general, the strain-hardening effect of an alloy can be measured by its strain-hardening exponent *n*, which is commonly calculated using the Hollomon relationship.[26]

The strain-hardening exponent of an alloy reflects the resistance of the alloy to sustained plastic deformation. For an ideal elastomer the strain-hardening exponent is equal to 1, which means the material has no strain hardening; for an ideal plastomer, the strain-hardening exponent is equal to 0, suggesting the material can continuously withstand plastic deformation. Actually, most metals and alloys have strain-hardening exponents between 0.1 and 0.5. The strain-hardening exponents for (5, 10 and 15) *x*/% SiCp/7055Al are summarized in **Table 1**. The strain-hardening exponents for all SiCp/7055Al decrease with increasing strain rates from

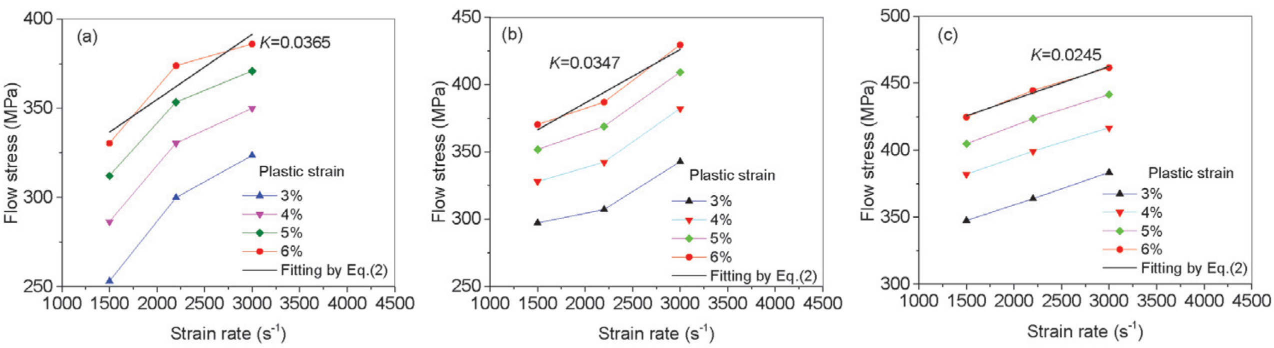

Figure 4: Variation of flow stress with strain rate at given plastic strains of SiCp/7055Al composite: a) 5 *x*/%, b) 10 *x*/%, b) 15 *x*/%

1500 s^{-1} to 3000 s^{-1}, and decrease with increasing volume fraction of SiCp from (5 to 15) x/%, which is due to the matrix being softened by the heat generated during dynamic compression.

Table 1: Strain-hardening exponent n for (5, 10 and 15) x/% SiCp/7055Al at various strain rates

Strain rate (s^{-1})	5 x/%	10 x/%	15 x/%
1500	0.115	0.104	0.06
2200	0.112	0.089	0.049
3000	0.101	0.062	0.035

We attempted the strain-rate sensitivity as follows[27]

$$\sigma_{d} = \sigma_{q} + K\dot{\varepsilon} \tag{2}$$

where σ_d, σ_q are the dynamic and quasi-static flow stresses at a constant plastic strain, respectively; $\dot{\varepsilon}$ is the strain rate and K is the rate-sensitivity parameter. Eq. (2) is constructed primarily based on the assumption that the dislocation-drag mechanism controls the deformation of metals at very high strain-rate deformation (usually $\dot{\varepsilon}$ > 1000 s^{-1}).[27] The flow stresses at 6 % strain are plotted as a function of strain rate, as illustrated in **Figure 4**. Marchi et al. and Zhang et al. suggested that the choice of 6 % strain was made so as to avoid the effect of the inhomogeneous deformation at lower strain during SHPB tests and to minimize the effect of damage accumulation and adiabatic heating at higher strain.[28,29] The strain-rate-sensitivity parameter K of the composites is determined from the slope of the linear regression line of the experimental results as shown in **Figure 4**. It is found that as the SiCp volume fraction increases, the strain-rate-sensitivity parameter K decreases. This result is consistent with that of Marchi et al. and Zhang et al.[28,29]

3.3 Microstructural Characterization

Figure 5 shows the microstructure of SiCp/7055Al composites fabricated by hot-press sintering. It can be seen that the SiCp distributes uniformly in the aluminium matrix. There are little voids or porosities in the

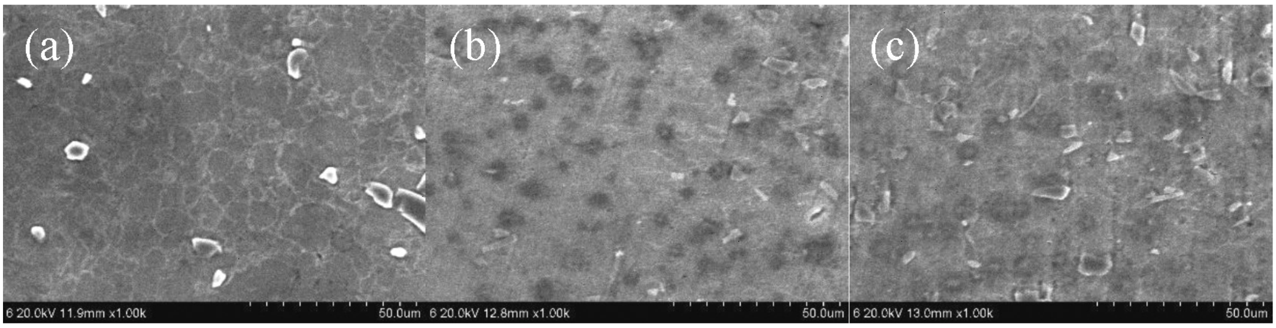

Figure 5: SEM micrographs of SiCp/7055Al composites before compression, a) 5 x/%, b) 10 x/%, c) 15 x/%

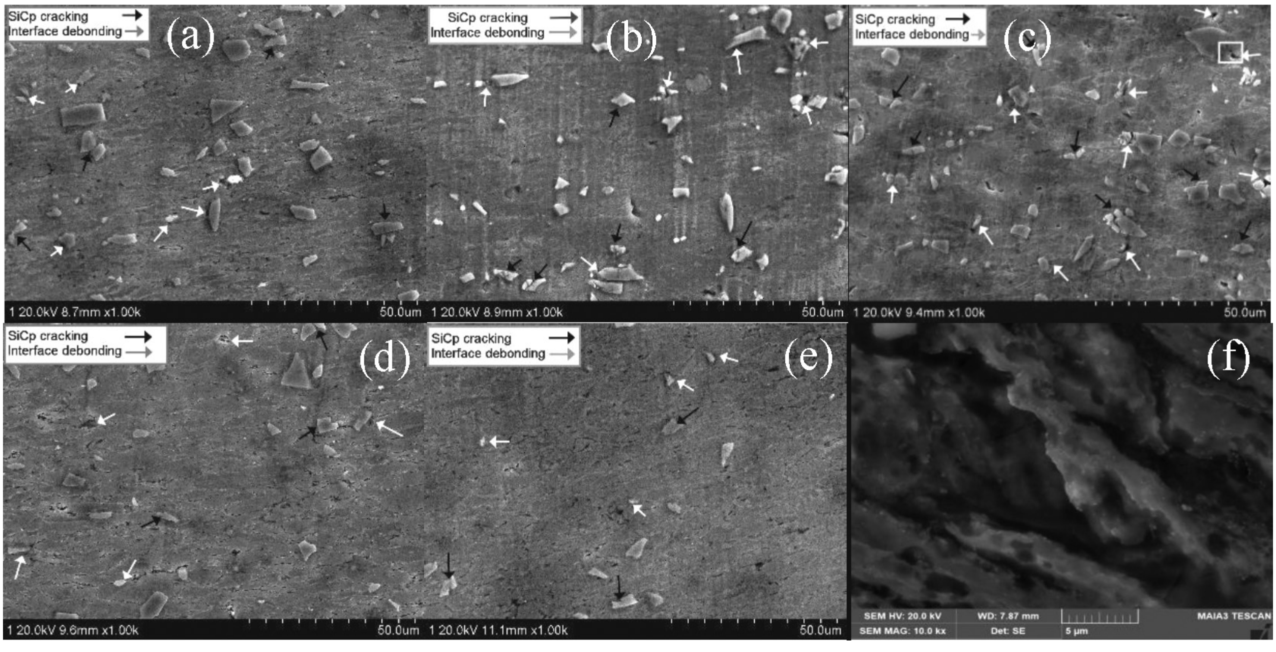

Figure 6: SEM micrographs of the dynamically compressed SiCp/7055Al composites with SiCp volume fraction of: a) 15 x/% at 1500 s^{-1}, b) 15 x/% at 2200 s^{-1}, c) 15 x/% at 3000 s^{-1}, d) 10 x/% at 3000 s^{-1}, e) 5 x/% at 3000 s^{-1}, f) Enlarged display of the box in (c).

composites. This indicates proper bonding of SiCp with the aluminium matrix.

After dynamic compression tests, the specimens were compressed into thin disks, neither obvious deformation band nor the adiabatic shear band was developed in the specimens. To reveal the damage mechanism of the SiCp/7055Al composites during dynamic compression, the cross-section of the dynamically compressed SiCp/7055Al composite specimens was acquired. Typical SEM micrographs of the dynamically compressed SiCp/7055Al composites with different SiCp volume fractions at various strain rates are shown in **Figure 6**. There are the two main modes of damage during the dynamic compression of composites, *i.e.*, SiCp cracking and SiCp/Al interface debonding, as indicated by the black and white arrows, respectively. From **Figure 6**, there were remarkable differences in the proportion of damaged SiCp in SiCp/7055Al composites with different particle fractions at various strain rates during dynamic compression. Comparing **Figure 6a**, **6b** and **6c**, the proportion of cracked and de-bonded SiCp with particle volume fraction of 15 % increased with an increase in the strain rate. During deformation, the matrix transfers stress to the particles due to the mismatch of the elastic moduli between the particle and the matrix. The higher flow stress of the matrix, the more stress will be transferred to the particles. So, the composites in service at higher strain rate have a higher flow stress. Cracked SiCp and interface debonding are more readily found in the composites at higher strain rates. Comparing **Figure 6c**, **6d**, and **6e**, the proportion of cracked SiCp and interface de-bonding at the same strain rate increased with an increase in SiCp volume fraction. Li and Ramesh believed that the flow stress increases with an increase in the particle volume fraction at high strain rate based on the unit-cell model of Al/SiCp composites reinforced with different particle volume fractions.[30] This is consistent with the experimental results shown in **Figure 2**. Sun et al. concluded that as particle cracking and interface failure occurred during the deformation process of the composite, the probabilities of particle cracking and interface failure also increased as the particle volume fraction increased.[25] The above analysis shows that the SiCp volume fraction and strain rate significantly affect the damage of composites during the dynamic compressive deformation of SiCp/7055Al composites, and the degrees of damage of SiCp inevitably influences the dynamic compressive properties of SiCp/7055Al composites. Moreover, **Figure 6f** shows the local enlarged view of interface debonding in **Figure 6c**, it is evident that the aluminium matrix is melted locally by heat produced during adiabatic compression. The local melted matrix cannot transfer stress any more, which results in specimens' damage at high strain rates. This agrees well with the decrease of flow stress at high strain rate in **Figure 1c**.

4 CONCUSIONS

The dynamic compressive properties of 7055 Al matrix composites reinforced with (5, 10 and 15) *x*/% SiCp at various strain rates were studied. The primary conclusions are as follows:

(1) The results showed that (5, 10 and 15) *x*/% SiCp/7055Al composites were strain-rate sensitive and the effect of strain rate hardening is stronger than strain hardening. The flow stress increased with increasing strain rates.

(2) The temperature rise during dynamic compression is theoretically in the range 30–62 K for SiCp/7055Al composites and increases with an increase of the strain rate, which causes a decrease of flow stress for (10 and 15) *x*/% SiCp at 3000 s^{-1} owing to the thermal softening of the Al matrix. Due to the extremely short adiabatic compression time, it is difficult to test. However, it is necessary to carry out experimental tests.

(3) As the SiCp volume fraction increases, the dynamic flow stresses of the composites increase significantly, while the strain-rate sensitivity decreases.

(4) SiCp cracking and SiCp/Al interface de-bonding are the main damage mechanisms of the composites. The SiCp volume fraction and strain rate affect the damage of composites during the dynamic compressive deformation of SiCp/7055Al composites, and the degrees of damage of SiCp inevitably influence the dynamic compressive properties of SiCp/7055Al composites.

5 REFERENCES

[1] T. Clyne, P. Withers, An Introduction to Metal Matrix Composites, Cambridge University Press, Cambridge, 1993

[2] J. P. Davim, Machining of metal matrix composites, London: Spring, 2012

[3] Yashpal, Sumankant, C. S. Jawalkar, A. S. Verma, N. M. Suri, Fabrication of Aluminium Metal Matrix Composites with Particulate Reinforcement: A Review, Materials Today: Proceedings 4 (**2017**), 2927–2936, doi:10.1016/j.matpr.2017.02.174

[4] B. S. Yigezu, P. K. Jha, M. M. Mahapatra, The Key Attributes of Synthesizing Ceramic Particulate Reinforced Al-Based Matrix Composites through Stir Casting Process: A Review, Materials and Manufacturing Processes, Processes, 28 (**2013**), 969–979, doi:10.1080/10426914.2012.677909

[5] S. Yadav, D. R. Chichili, K. T. Ramesh, The mechanical response of a 6061-T6 Al/Al_2O_3 metal matrix composite at high rates of deformation, Acta metall, mater. 43 (**1995**), 12, 4453–4464, doi:10.1016/0956-7151(95)00123-D

[6] X. G. Xue, L. J. Xie, T. Wang, Study on the constitutive model of SiCp/Al composites, Key Eng. Mater. 693 (**2016**), 621–628, doi:10.4028/www.scientific.net/KEM.693.621

[7] Y. Li, K.T. Ramesh, E.S.C. Chin, The compressive viscoplastic response of an A359/SiCp metal–matrix composite and of the A359 aluminum alloy matrix, Int. J. Solids Struct. 37 (**2000**) 51, 7547–7562, doi:10.1016/S0020-7683(99)00304-2

[8] A. Kalambur, I. W. Hall, Dynamic compressive behavior of a SiCw/Al composite, Scr. Mater., 37 (**1997**) 2, 193–198, doi:10.1016/S1359-6462(97)00083-3

[9] D. F. Cao, W. C. She, L. S. Liu, P. C. Zhai, Q. J. Zhang, Effect of particle size on the dynamic mechanical behaviour and deformed

microstructure of SiCp/Al composites, IOP. Conf. Ser.: Mater. Sci. Eng., 18 (**2011**) 20, 202014, doi:10.1088/1757-899X/18/20/202014

[10] H. Lee, S. S. Sohn, C. Jeon, I. Jo, S. K. Lee, S. Lee, Dynamic compressive deformation behavior of SiC-particulate-reinforced A356 Al alloy matrix composites fabricated by liquid pressing process, Mater. Sci. Eng. A, 680 (**2017**), 368–377, doi:10.1016/j.msea.2016.10.102

[11] H. Lee, J. H. Choi, M. C. Jo, D. Lee, S. Shin, I. Jo, S. K. Lee, S. Lee, Effects of SiC particulate size on dynamic compressive properties in 7075–T6 Al-SiCp composites, Mater. Sci. Eng. A, 738 (**2018**), 412–419, doi:10.1016/j.msea.2018.09.082

[12] H. Lee, J. H. Choi, M. C. Jo, I. Jo, S. K. Lee, S. Lee, Effects of Strain Rate on Compressive Properties in Bimodal 7075 Al–SiCp Composite, Met. Mater. Int., 24 (**2018**), 894–903, doi:10.1007/s12540-018-0092-9

[13] D. J. Lloyd, Particle reinforced aluminium and magnesium matrix composites, Int.Mater. Rev., 39 (**1994**), 1–23, doi:10.1179/imr.1994.39.1.1

[14] R. Kitey, H. V. Tippur, Role of particle size and filler–matrix adhesion on dynamic fracture of glass-filled epoxy. I. Macromeasurements, Acta Mater., 53 (**2005**), 1153–1165, doi:10.1016/j.actamat.2004.11.012

[15] W. Chen, B. Song, Split Hopkinson (Kolsky) Bar-Design, Testing and Applications, Springer, New York, 2011

[16] R. Gerlach, C. Kettenbeil, N. Petrinic, A new split Hopkinson tensile bar design, Int. J. Impact Eng. 50 (**2012**), 63–67, doi:10.1016/j.ijimpeng.2012.08.004

[17] M. Kang, J. Park, S.S. Sohn, H. Kim, K. H. Kim, S. Lee, Adiabatic shear banding and cracking phenomena occurring during cold-forging simulation tests of plain carbon steel wire rods by using a split Hopkinsons pressure bar, Met. Mater. Int., 21 (**2015**), 991–999, doi:10.1007/s12540-015-5252-6

[18] Z. H. Tan, B. J. Pang, B. Z. Gai, G. H. Wu, B. Jia, The dynamic mechanical response of SiC particulate reinforced 2024 aluminum matrix composites, Materials Letters, 61 (**2007**), 4606–4609, doi:10.1016/j.matlet.2007.02.069

[19] Z. H. Tan, B. J. Pang, D. T. Qin, J. Y. Shi, B. Z. Gai, The compressive properties of 2024Al matrix composites reinforced with high content SiC particles at various strain rates, Materials Science and Engineering A, 489 (**2008**), 302–309, doi:10.1016/j.msea.2007.12.021

[20] T. Ye, L. Li, P. Guo, G. Xiao, Z. Chen, Effect of aging treatment on the microstructure and flow behavior of 6063 aluminum alloy compressed over a wide range of strain rate, Int. J. Impact Eng., 90 (**2016**), 72–80, doi:10.1016/j.ijimpeng.2015.12.005

[21] Y. Yang, J. L. Wang, Y. D. Chen, H. B. Hu, Effect of strain rate on microstructural evolutions and thermal stability of 1050 commerical pure aluminum. Transactions of Nonferrous Metals Society of China, 28 (**2018**) 1, 1–8, doi:10.1016/S1003-6326(18)64632-1

[22] S. Heilmann, D. KöBerlin, M. Merx , M.Jens, J. Zschetzsche, S. Ihlenfeldt, U. Füssel, Numerical and experimental analysis on the influence of surface layer on the resistance spot welding process for the aluminum alloys 5182 and 6016, Weld World, 63 (**2019**), 1205–1220, doi:10.1007/s40194-019-00743-y

[23] Y. S. Touloukian , E. H. Buyco, Thermophysical Properties of Matter – the TPRC Data Series, Vol. 5. Specific Heat – Nonmetallic Solids. 1970

[24] C. Zhou, G. Ji, Z. Chen, M. Wang, A. Addad, D. Schryvers, H Wang, Fabrication, interface characterization and modeling of oriented graphite flakes/Si/Al composites for thermal management applications, Materials & Design, 63 (**2014**), 719–728, doi:10.1016/j.matdes.2014.07.009

[25] W. Sun, C. Z. Duan, W. D. Yin, Development of a dynamic constitutive model with particle damage and thermal softening for Al/SiCp composites, Composite Structures, 236 (**2020**), 111856, doi:10.1016/j.compstruct.2020.111856

[26] J. H. Hollomon, Tensile deformation, Trans. AIME, 162 (**1945**), 268–290

[27] I. Tirtom, M. Guden, H. Yildiz, Simulation of the strain rate sensitive flow behavior of SiC-particulate reinforced aluminum metal matrix composites, Comput. Mater. Sci., 42 (**2008**), 570–578, doi:10.1016/j.commatsci.2007.09.005

[28] C. S. Marchi, M. F. Cao, A. Kouleli, Mortensen, Quasistatic and dynamic compression of aluminum-oxide particle reinforced pure aluminum, Mater. Sci. Eng. A, 337 (**2002**), 202–211, doi:10.1016/S0921-5093(02)00035-7

[29] J. T. Zhang, H. J. Shi, M. C. Cai, L. S. Liu, P. C. Zhai, The dynamic properties of SiCp/Al composites fabricated by spark plasma sintering with powders prepared by mechanical alloying process, Mater. Sci. Eng. A, 527 (**2009**), 218–224, doi:10.1016/j.msea.2009.08.067

[30] Y. Li, K.T. Ramesh, Influence of particle volume fraction, shape, and aspect ratio on the behavior of particle-reinforced metal–matrix composites at high rates of strain, Acta Mater, 46 (**1998**)16, 5633–5646, doi:10.1016/S1359-6454(98)00250-X