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Microstructural and Mechanical Properties Study of Al/SiC composite prepared by PM technique

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Abstract

The present work investigates the optimal effect of SiC addition on the mechanical and microstructure properties of Al/SiC composites. The samples were prepared using powder metallurgy (PM) technique. Different weight percentages ranging from 10% to 50% of SiC powder were added and mixed with Al. The particle size of SiC particulates ranged between 20 and 45 µm. The subsequent mixture was poured into a cylindrical steel mould and pressed to obtain cylindrical shape samples of 10 mm in diameter. The prepared compact samples were sintered at a temperature of 650˚C. The influence of adding different weight percentages of SiC on the microstructure and mechanical characteristics of the composite was investigated. The XRD diffraction and SEM micrographs specified that Al and SiC were the main components in the composite. Ultimate strength was obtained for the addition of 20wt%SiC. Micro-hardness decreased due to porosity in proportionality to SiC content and the intermetallic phase formation. The present investigation showed that the optimum increase in microhardness was achieved between 20 to 40wt% of SiC, while the minimum hardness was at more than 40% SiC. On the other hand, the ultimate compressive strength was achieved between 10 to 30wt% of SiC and minimum compressibility was obtained at 50% SiC. Thus, the excessive addition of SiC leads to adverse results since it affects the composite porosity.

Keywords: Al/SiC; composites; compression; micro hardness; powder metallurgy.

دراسة الخصائص التركيبية والميكانيكية للمركب Al/SiC المحضر بواسطة طريقة المساحيق

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الخلاصة

يكرس العمل الحالي لدراسة التأثير الأمثل لإضافة جزيئات SiC على الخواص الميكانيكية والتركيبية الدقيقة لمركبات Al/SiC. تم تحضير العينات باستخدام تقنية المساحيق. مسحوق SiC بنسب وزنية مختلفة تتراوح من

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0 إلى 50 يضاف إلى مادة Al ثم يخلط معه. تحتوي جسيمات SiC على أحجام جسيمات تتراوح من 20 إلى 45 ميكرومتر. تم صب الخليط اللاحق في قالب فولاذي أسطواني وضغطه للحصول على عينات أسطوانية قطرها 10 مم. تم تلبيد العينات المدمجة المحضرة عند درجة حرارة 650 درجة مئوية. درس تأثير إضافةSiC على البنية المجهرية والتوصيف الميكانيكي للمركب. اظهر قياس حيود الاشعة السينية XRD والتصوير المجهري SEM أن Al وSiC هما المكونان الرئيسيان. تم الحصول على القوة القصوى لـ SiC بنسبة 20% بالوزن. حدث انخفاض في الصلابة الدقيقة بسبب المسامية المتناسبة مع محتوى SiC وتكوين الطور بين المعادن. أظهر البحث الحالي أن الزيادة المثلى في الصلابة قد تم تحقيقها بين 20 إلى 40% بالوزن من SiC بينما تم تحقيق الحد الأدنى من الزيادة بأكثر من 40%. من ناحية أخرى، تم تحقيق قوة الضغط القصوى بين 10 إلى 30% بالوزن من SiC والحد الأدنى للانضغاط. تم الحصول عليه عند SiC بأكثر من 30% بالوزن. وبالتالي، فإن الإضافة المفرطة لـ SiC تؤدي إلى نتائج عكسية. لأنه يؤثر على مسامية المركب.

1. Introduction

Metal Matrix Composites (MMCs) have received impressive attention due to their multiple applications in several fields, such as the automotive industries, the aerospace sector, automobile, and consumer electronics gadgets. Al/SiC composites are MMCs made of hard silicon carbide particles reinforcing aluminium powder. They are suitable for numerous strength components requiring high stiffness because of their characteristics combination of low-cost production, high strength and high heat resistance. However, these materials have low strength and low hardness. Therefore, it is necessary to enhance their mechanical and physical properties to fully exploit the ability of this category of materials. Enhancing the mechanical characteristics of particle composites can be done in various ways. This study uses microstructural parameters (such as reinforcement size and matrix characteristics) to enhance hardness and compression fracture qualities.

In general, Al-SiC and Al-Cu are used as aluminum matrices. Aluminum Matrix Composites (AMCs) should be identified by their constituents, accepted designation of the matrix abbreviation of the reinforcement's designation arrangement and %volume fraction with symbol for type and shape of reinforcement, as suggested by the American Aluminum Association [1,2]. Like other composites, aluminum-matrix composites (AMCs) are mixtures of two or more materials. The stiffness, density, thermal, and mechanical characteristics of a matrix material are boosted by a reinforced material, such as ceramics, which have better mechanical properties. The strengthening material, volume fraction, reinforcing particles state, reinforcement location and preparation technique can be controlled entirely to attain the required properties. The purpose of fabricating metal matrix ceramic material is to merge the required properties of ceramics and metals by adding high modulus, high strength, and high stiffness material to ductile metal whose mechanical properties probably require enhancement. Metals have many desirable properties, such as high strength, high density, and high heat conductivity, but at the same time, they have low hardness, low stiffness and brittle; for this reason, they should be blended with non-metal materials, such as ceramics [3,4,5,6]. Aluminum Metal Matrix Composites (AMMCs) consist of a new generation of engineering materials that have received extensive scrutiny since the trial offered by TOYOTA company in the 1980s. Silicon carbide is the most desirable reinforced material since it has desirable properties such as high stiffness and lightweight.

The current research aimed to investigate the structural and mechanical properties of aluminum-silicon carbide composites manufactured using the powder technology method. The composite samples were prepared by mixing aluminum powder with different concentrations of silicon carbide particles with weight ratios from 10 to 50wt%, and a particle size of less than 45 microns.

2. Materials and Methods

Aluminum Al and silicon carbide (SiC) were provided by Fluka Chemie AG and HiMedia laboratories, Pvt. Ltd., respectively, with aluminum particle size <45µm and silicon carbide particle size <25µm. Aluminum and different percentages of silicon carbide (0wt%,10wt%,20wt%,30wt%, 40wt%, and 50wt%) were mixed, and PVA was added as a binder. The mixture was blended mechanically by mortar for 5 minutes, and the mixture was poured into a cylindrical steel mould and pressed for 2 minutes with a compressive force of 8 tons to obtain cylindrical shape samples of 10 mm in diameter. Samples were sintered at 650^{o}C at a vacuum furnace for 2 hours. A hardness test was carried out using Vicker indentation (tester TH714, Holland) at applied forces with wights 100gm and 200gm, and the compression was carried out using a Mel system (made in Germany). Samples were crushed and milled into powder using an agate mortar. After that, an XRD examination was performed on the powder.

3. Results and discussion

3.1 X-Ray Diffraction (XRD) analysis

Figure 1 shows XRD patterns for Al/SiC composite with (0wt%,10wt%,20wt%,30wt%, 40wt%, and 50wt% SiC). The pure sample (0wt% SiC) showed many peaks corresponding to 101 and 111, identical to the cubic Al structure with standard card no. 96-901-2004. There were no remarkable changes in the XRD patterns of Al/10%SiC and Al/20%SiC until SiC concentration reached 30wt%, where new peaks related to SiC structure were noticed, and as SiC reached 50wt%, the number of peaks remarkably increased. The appearance of new peaks after adding SiC is consistent with the many studies [7,8].

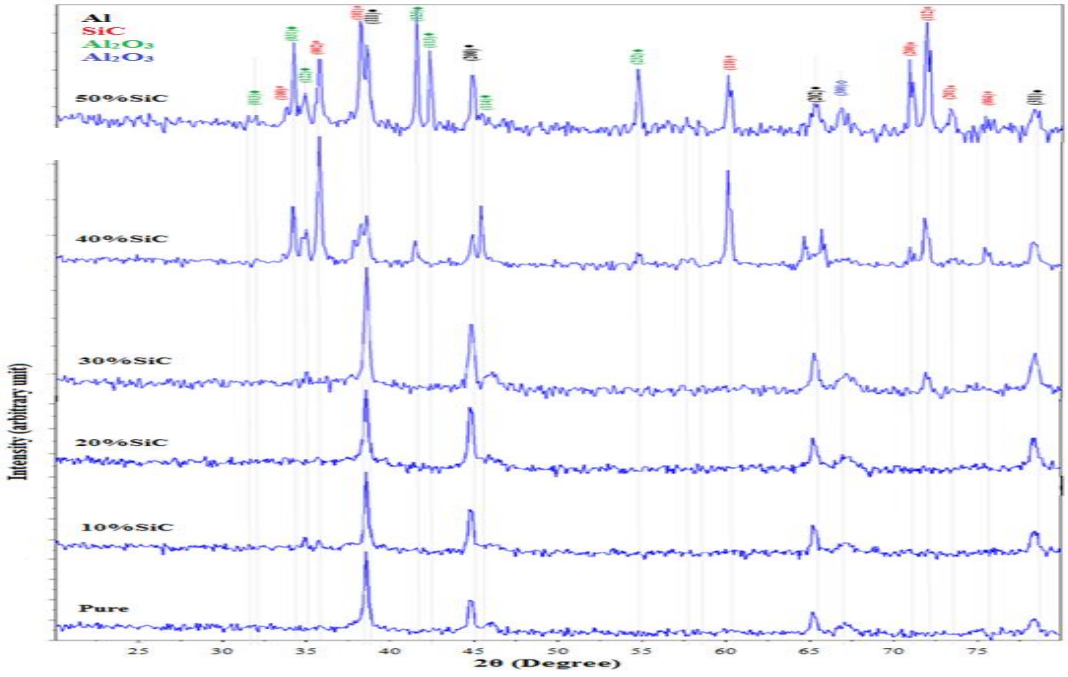
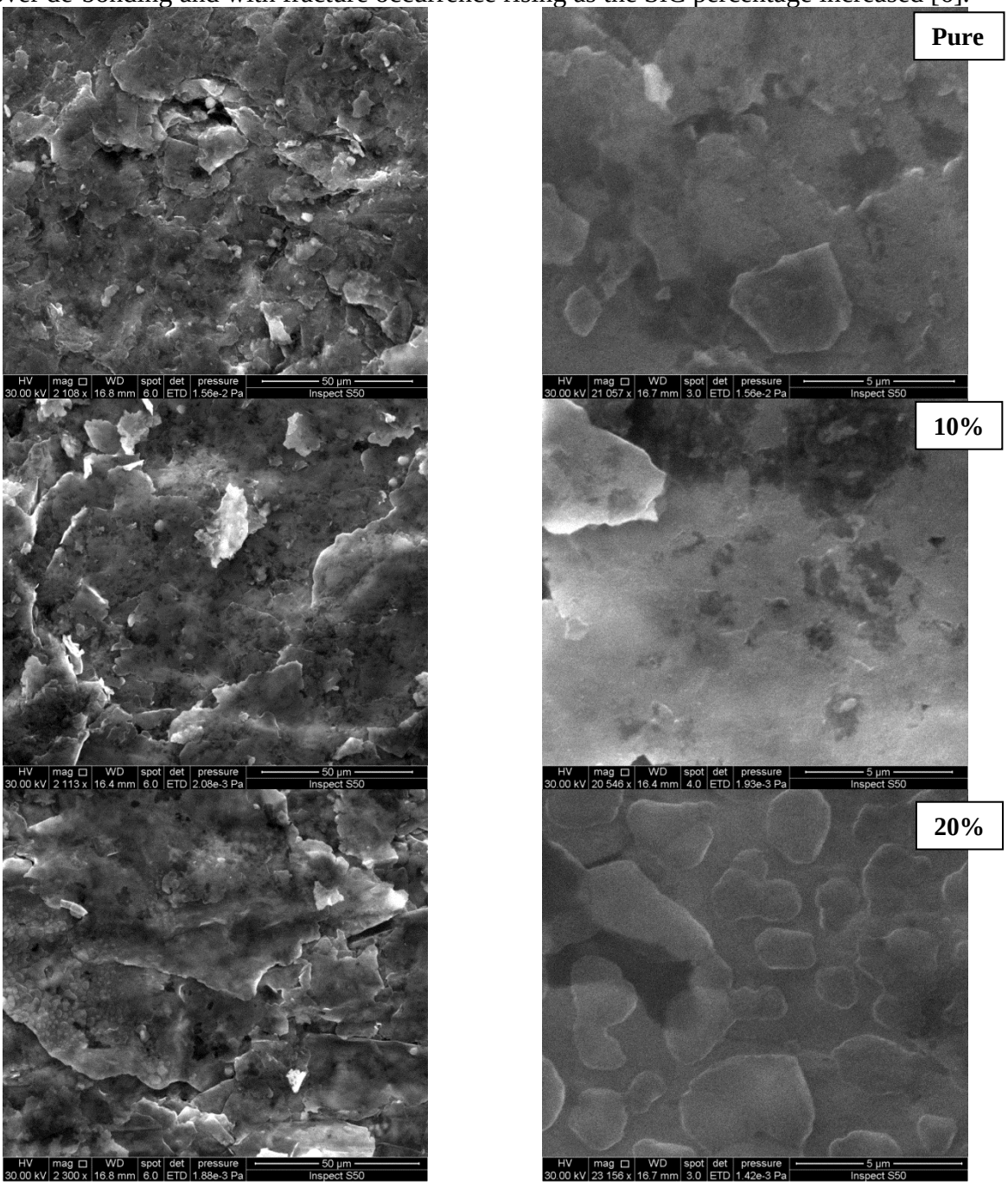


Figure 1: XRD patterns for Al/SiC composite with different percentages of SiC.

3.2 Scanning electron microscopy (SEM)

The microstructure images of the Al/SiC composites with different percentages of SiC are presented in Figure 2 at zoom ratios of 5µm and 50µm. In the images, dark grey indicates SiC particles, and lighter grey represents the Al matrix. As seen in Figure 2, the SiC particles are randomly spread throughout the Al matrix. At the cross-sections of these samples, no glaring evidence of heterogeneities in the distribution of SiC reinforcement particles was found. The

agglomeration of SiC particles in the Al matrix cannot be prevented completely, especially in 40wt% and 50wt% SiC. It could be observed that an intense amount of SiC clustering may adversely result in non-homogeneity of the SiC distribution and cause a decrease in the mechanical and physical properties of the Al/SiC composites. The amount of SiC clustering increased with increasing the SiC percentage for all samples. Additionally, to the existence of interface, SEM images showed SiC fracture and de-bonding, with particle fracture dominating over de-bonding and with fracture occurrence rising as the SiC percentage increased [6].



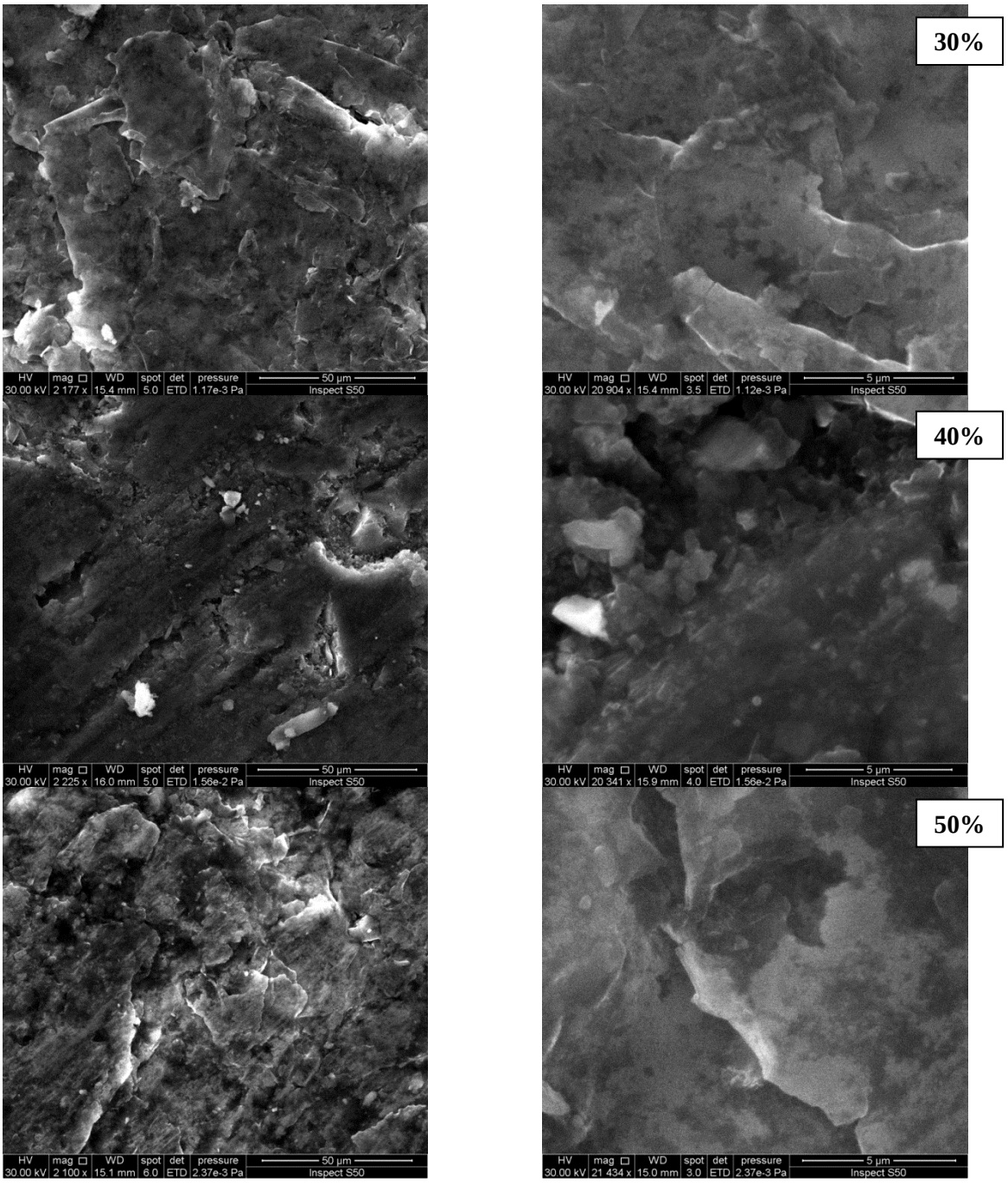


Figure 2: SEM images of pure Al and Al/SiC composites of different SiC percentages, at zoom ratios of 5μm and 50μm.

3.3 EDX-Ray Spectroscopy Measurements

Energy Dispersive X-ray (EDX) micrographs of Al particles and Al/SiC composites of different SiC percentages (10wt%,20wt%,30wt%,40%, and 50wt%) are shown in Figure (3-a, b, c, d, e, and f) and explained in Table 1. They suggest the samples' chemical purity and stoichiometry. The spectra showed strong peaks related to Al and Si, providing unmistakable proof that Al, Si, and C components were present.

The gradual decrease in aluminum concentration and the gradual increase in silicon and carbon concentrations in the new mixed and compressed material is evidence of regular arrangement and mixing. The presence of impurities or contamination during the preparation

process is the reason for the appearance of Ca, Sb, and O in the spectra, which is consistent with other research [9].

Table 1: EDX table of Al pure and of Al/SiC composites at different concentrations of SiC.

Materials	Pure	10%	20%	30%	40%	50%
Aluminiums concentration	79.64	73.2	60.27	59.73	48.5	46.4
Peaks strong	34	33	31	30	24	17
Silicons concentration	0.51	1.01	7.62	4.73	6.3	33.4
Carbons concentration	4.63		11.83		4.8	9.0

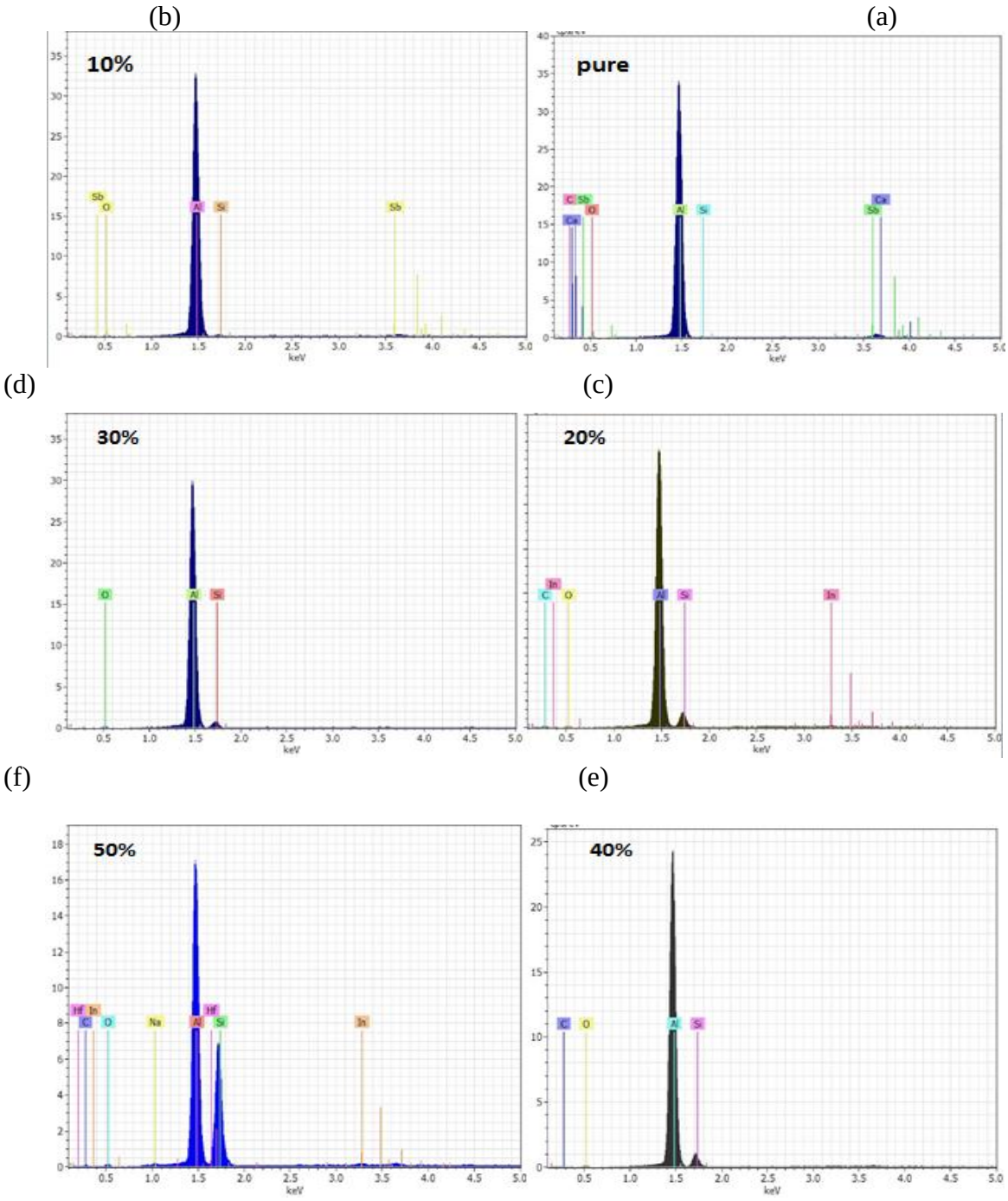


Figure 3: EDX micrographs of (a) pure Al and (a,c,d,e,f) Al/SiC composites at different concentrations of SiC.

3.4 Relative density

Maximum green density was attained at a compaction pressure of 8 tons. After sintering, samples experienced volume shrinkage of roughly 2.1%, and the density was closer to 92% of the theoretical density. The diameter of the samples in this experiment was 10 mm. The calculated density (ρC) is defined as [10]:

$$\rho C = \frac{\rho 1 \rho 2}{x1\rho 2 + x2\rho 1} * 100\% \quad \ldots\ldots (1)$$

Where: ρ_1 is the aluminum density, ρ_2 is the silicon carbide density, X_1 and X_2 are the weight percentage of aluminum and silicon carbide.
The true density (ρ formula is:

$$\rho = \frac{M}{V} \quad \ldots\ldots\ldots (2)$$

Where: M is the weight (in gm) of the sample after compacting, and V is the volume (in cm^3)of the sample. The relative density has been calculated by dividing the true density by the calculated density. The relative density of pure Al was found to be 97.2%, and the densities of composites decreased from 95.3% to 86.5% as the concentration of SiC increased from 10wt% to 50wt%, as shown in Table 2, and Figure. 4. This change is because the density of Al is much lower than that of SiC. In samples with low SiC percentage, less interstices means less SiC dispersion. Al particles can disperse promptly and occupy the voids between the SiC particles, thus resulting in composite solidification [11].

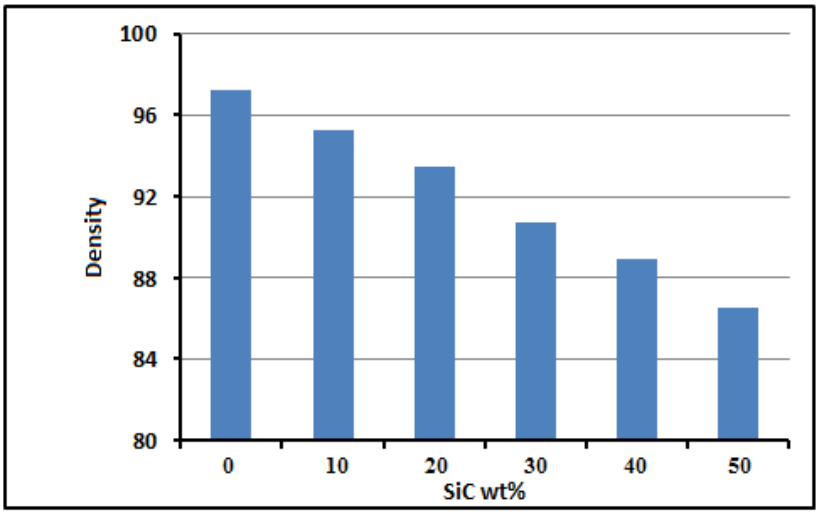


Figure 4: Density of Al and Al/SiC composite versus different SiC percentage.

3.5 Hardness

The influence of the different percentages of SiC on the micro-hardness of the Al/SiC sample is evident, as shown in Table 2. Hardness test was carried out using Vicker indentation at applied forces with weights (P) 100gm and 200gm for 15sec. Table 2 shows that the hardness value of the pure Al sample at weight 100gm are greater than 200gm Figure 5 shows The micro-hardness values of Al/SiC composite with different SiC percentages were greater than that of pure Al since adding SiC particles improves the hardness of the composite [12], and that the hardness values at 200gm weight are higher than those at 100gm weight. From this figure, as the SiC percentage increased from 10wt% to 50wt%, the hardness rose significantly; the highest micro-hardness value was at 50wt% SiC at 200gm weight. The arbitrary diffusion of SiC

particles within the Al matrix mainly caused work hardening, leading to the highest micro-hardness. Nevertheless, increasing SiC percentage caused clustering of the SiC particles around the Al particles, leading to non-homogeneity and agglomeration in the composite, which caused surface fracture during the hardness test. The increase in the micro-hardness of such composites with the SiC content can be ascribed to the dispersion-strengthening effect.

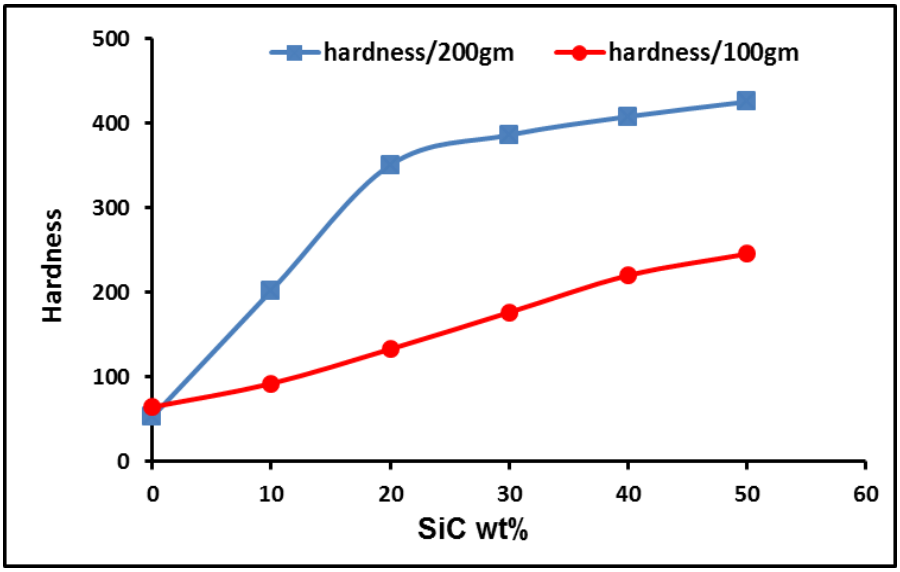


Figure 5: Hardness of Al/SiC composite versus various SiC percentage.

3.6 Compression

The compression yield stress was calculated from stress-strain curves; the results are shown in Table 2 and Figure 6. The addition of SiC particles substationally influenced the yield values of strength. The yield strength of pure Al was 196.82MPa. It increased with the increase of the SiC percentage, reaching a maximum of 294.20MPa at 30% SiC, after which it decreased with further increase of SiC. This shows that the threshold value of SiC content to obtain maximum compression was approximately 30 percent.

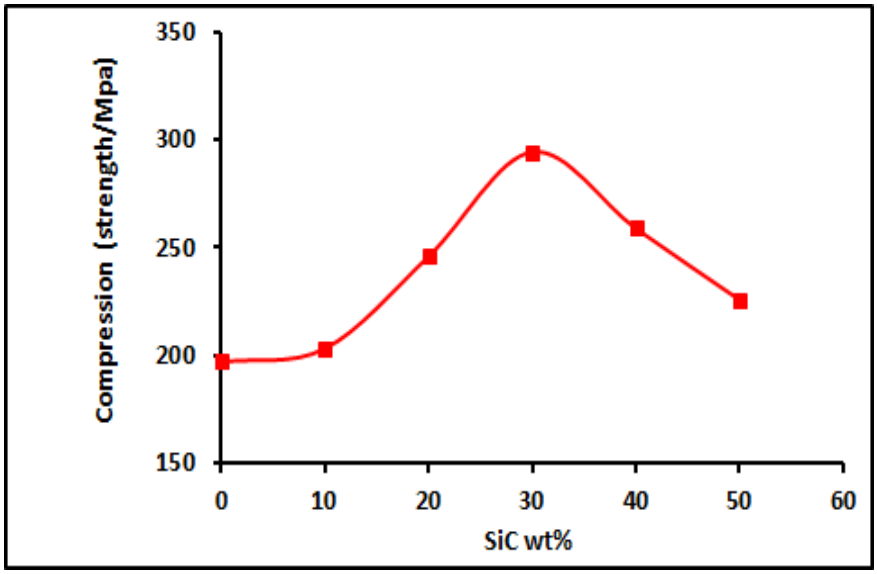


Figure 6: Compression of Al/SiC composite versus various SiC percentage.

Table 2: Relative density, Vickers hardness and compression.

SiC wt%	%Relative density	Hardness (t=15 sec)		Compression strength (MPa)
		p=200gm	p=100gm	
0	97.2	53.31	65	196.82
10	95.3	202.5	93	203.07
20	93.5	351.13	133	245.79
30	90.7	386.5	177	294.20
40	88.9	408.3	220	258.70
50	86.5	425.8	246	225.60

4. Conclusion

From the results of this study, the following points can be concluded**:**

1- The porosity of Al/SiC composite increased as SiC content increased. For the 50wt% percentage, the relative density decreased to 86.5%; the main reason is that the density of SiC particles is higher than that of Al, leading to high porosity and less sample hardening.

2- SiC particle agglomeration in the Al matrix cannot be completely prevented, especially in 40wt% and 50 wt% SiC percentages. It was also observed that a higher percentage of SiC clustering leads to the inhomogeneity of the SiC distribution, also decreasing the physical and mechanical properties of Al/SiC matrix.

3- It is established that the average micro-hardness Al/SiC composite increased with the increase in SiC content, which can be ascribed to the dispersion strengthening effect. The highest increase in micro-hardness value was at 50wt% SiC. The micro-hardness of Al/SiC composite was greater than that of Al; adding SiC particles improved the hardness of the composite.

4- The compressibility of 30% SiC reached 294.2MPa compared to 225 MPa of the 50wt% SiC; at the higher SiC content (40wt% and 50wt% (compressibility was lower due to porosity content.

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