Metallophysics and Advanced Technologies
Металофіз. новітні технол.
Metallofiz. Noveishie Tekhnol.
2020, vol. 42, No. 4, pp. 565–573
https://doi.org/10.15407/mfint.42.04.0565
Reprints available directly from the publisher

STRUCTURE AND PROPERTIES OF NANOSCALE AND MESOSCOPIC MATERIALS

PACS numbers: 61.66.Dk, 61.72.Qq, 62.20.Qp, 81.05.Ni, 81.20.Ev

Investigation of Graphite Influence on Al/Fe and Al2024/Fe Metal Matrix Composites

K. Santhy[*,**]

[*]*CARE Group of Institutions,*
Department of Materials Science and Engineering,
No. 27, Thayanur, Tiruchirappalli-620009, Tamil Nadu, India
[**]*Indus University, Institute of Technology and Engineering,*
Department of Materials and Metallurgical Engineering,
Rancharda, Ahmedabad-382115, India

Aluminium and aluminium alloy composites are a new generation metal matrix composite which have potential to satisfy the recent demands of advanced engineering applications. To improve the mechanical properties of Al/Al2024 alloys, iron and graphite reinforcements are selected for hybrid composite. To maintain the low density of the matrix, iron content is fixed as 4% wt. and graphite content is varied from 5 to 8% wt. Using optimized compaction load and sintering temperature, the Al–Fe–Graphite and Al2024–Fe–Graphite hybrid composites are fabricated by powder metallurgy process. The elemental powders and sintered products are characterized with the help of X-ray diffraction and scanning electron microscopy. The addition of graphite not only increases the density, it also increases the hardness of the hybrid composites. In comparison with Al hybrid composites, the Al2024 hybrid ones have better mechanical property.

Key words: Al and Al2024 alloy, graphite contained hybrid composite, mechanical property, powder metallurgy.

Композити на основі алюмінію та алюмінієвих стопів є металевими матричними композитами нового покоління, які можуть задовольнити останні вимоги новітніх інженерних застосувань. З метою поліпшення механічних властивостей стопів Al/Al2024 для гібридних композитів використо-

Corresponding author: K. Santhy
E-mail: k_santhy@rediffmail.com

Citation: K. Santhy, Investigation of Graphite Influence on Al/Fe and Al2024/Fe Metal Matrix Composites, *Metallofiz. Noveishie Tekhnol.*, **42**, No. 4: 565–573 (2020), DOI: 10.15407/mfint.42.04.0565.

вувались залізо та графіт у якості армуючих добавок. Для збереження низької густини матриці вміст заліза залишався сталим та складав 4% мас., а концентрація графіту варіювалася від 5 до 8% мас. Шляхом оптимізації ущільнюючого навантаження та температури спікання гібридні композити Al–Fe–графіт та Al2024–Fe–графіт було виготовлено методом порошкової металургії. Елементарні порошки та спечені продукти характеризувалися за допомогою Рентґенової дифракції та сканувальої електронної мікроскопії. Додавання графіту збільшує не тільки густину, а й твердість гібридного композиту. Гібридні композити Al2024 мають кращі механічні властивості порівняно з гібридними композитами на основі Al.

Ключові слова: стопи Al та Al2024, графітовмісний гібридний композит, механічні властивості, порошкова металургія.

Композиты на основе алюминия и алюминиевых сплавов являются металлическими матричными композитами нового поколения, которые могут удовлетворить последние требования новейших инженерных приложений. С целью улучшения механических свойств сплавов Al/Al2024 для гибридных композитов использовались железо и графит в качестве армирующих добавок. Для сохранения низкой плотности матрицы содержание железа оставалось постоянным и составляло 4% масс., а концентрация графита варьировалась от 5 до 8% масс. Путем оптимизации уплотняющей нагрузки и температуры спекания методом порошковой металлургии были изготовлены гибридные композиты Al–Fe–графит и Al2024–Fe–графит. Элементарные порошки и испечённые продукты характеризовались с помощью рентгеновской дифракции и сканирующей электронной микроскопии. Добавление графита увеличивает не только плотность, но и твёрдость гибридного композита. Гибридные композиты Al2024 имеют лучшие механические свойства в сравнении с гибридными композитами на основе Al.

Ключевые слова: сплавы Al и Al2024, графитсодержащий гибридный композит, механические свойства, порошковая металлургия.

(Received June 1, 2019; in final version, January 20, 2020)

1. INTRODUCTION

Metal matrix composite materials are finding increased application in aerospace and automobile industries due to their enhanced properties such as high strength, high stiffness, and good wear resistance. Hybrid composite materials are advanced composite materials reinforced with more than one reinforcement materials in order to achieve the mechanical properties such as hardness, tensile strength at room and elevated temperature. This gives rather high degree of freedom in material design. The final properties of the hybrid reinforcement depend on individual properties of the selected reinforcement and matrix materials.

Aluminium based particulate reinforced composites are class of composite having high desirable properties in engineering applications. The mechanical and tribological properties of the matrix material was improved by reinforcing the various reinforcements ranging from very soft materials like Graphite, Talc *etc.* [1], to high hardened ceramic particulates like SiC, Al_2O_3, *etc.* Among the various aluminium 2024 alloys is typically characterised by properties such as fluidity, cast ability, corrosion resistance and high strength to weight ratio. The chemical composition of Al2024 is listed in Table 1. This alloy commonly acts as matrix and reinforced with different fibres, particles and whiskers [2–4].

In the present investigation aluminium and aluminium alloy 2024 are used as matrix material. One of reinforce material is iron with fixed composition of 4% which improves the high temperature properties. In most of earlier investigations, related Al–Fe binary system, are focused either liquid-phase sintering or iron-rich composition (more than 20% wt. Fe) [5, 6]. The hike of density due to Fe addition was compensated by addition of graphite (Gr).

Present work concentrate to understand the effect of graphite in Al–4Fe and Al2024–4Fe hybrid composite in mechanical properties such as hardness processed through powder metallurgy route. The chosen matrix and reinforcement materials properties are listed in Table 2. The alloying element in Al2024 falls within the solvus line. Hence, Al and Al2024 are having the same crystal structure. Powder metallurgy process avoids the formation of equilibrium binary intermediate phases such Al_4C_3, Al_3Fe and Fe_3C.

2. EXPERIMENTAL DETAILS

In present study, pure aluminium, graphite, commercial Al2024 and

TABLE 1. Chemical composition (in % wt.) of Al2024 alloy powder.

Al	Fe	Mn	Cu	Mg	Cr	Si
90.7–94.7	0.5 max	0.15 min	3.4–4.9	1.2–1.8	0.1 max	0.05 max

TABLE 2. Physical properties of selected matrixes and reinforcements.

Element	Density, g/cm^3	Crystal structure	T_m, °C
Al	2.7	f.c.c.	660
Al2024	2.78	f.c.c.	502–638
Fe	7.89	b.c.c.	1538
Graphite	2.25	Hexagonal	3650

iron powder are selected to produce composite materials. Pure Al and commercial Al2024 powders are used as a matrix; Fe and Gr powders are act as reinforced materials.

The selected chemical composition for this work is shown in Tables 3 and 4. Powder mixtures with different chemical compositions are mixed thoroughly to attain a homogeneous mixture. The mixed powders are subjected to uniaxial compaction followed by sintering in muffle furnace to prepare the cylindrical pellets at 10 mm diameter and 5 mm height. The compaction load and temperature are optimized with respect to density. The compaction load range is selected from 200 to 240 kN with the increment of 10 kN (shown in Fig. 1) and fixed as 230 kN. Similar procedure is adopted for sintering temperature. The temperature, 450 to 600°C range was selected with increment of 50°C with the soaking period of 1 h. Due to discrepancy in density around 500–550°C (Fig. 2) with present composition and instrumental facility, sintering temperature is fixed at 600°C.

After sintering, the density of specimens is determined by Archimedes' principle. The theoretical density of hybrid composite is calculated by rule of mixtures using density and volume fraction of matrix and reinforced materials.

For metallographic examination, the specimens are polished as per

TABLE 3. Comparison of experimental and theoretical density of Al–Fe–Gr composites.

No.	Composition, % wt.			Density, g/cm^3		Densification, %
	Al	Fe	Gr	Theoretical	Exp.	
1	91	4	5	2.745	2.490	90.696
2	90	4	6	2.740	2.478	90.448
3	89	4	7	2.735	2.500	91.421
4	88	4	8	2.729	2.492	91.293

TABLE 4. Comparison of experimental and theoretical density of Al2024–Fe–Gr composites.

No.	Composition, % wt.			Density, g/cm^3		Densification, %
	Al	Fe	Gr	Theoretical	Exp.	
1	91	4	5	2.820	2.475	87.749
2	90	4	6	2.814	2.450	87.066
3	89	4	7	2.807	2.428	86.467
4	88	4	8	2.801	2.418	86.311

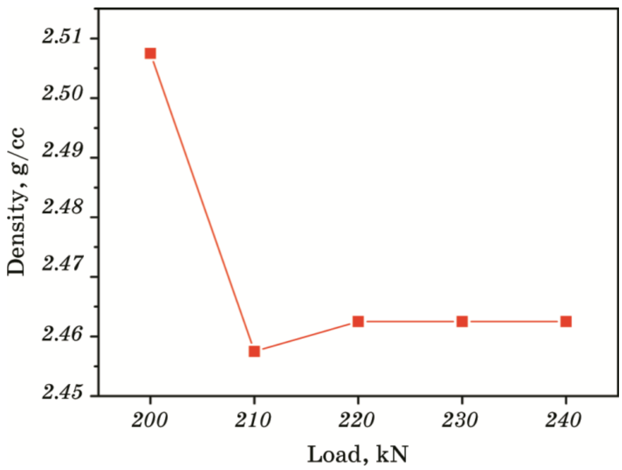


Fig. 1. Compaction load optimization with respect to density for Al–4Fe–5Gr sample.

standard procedure. The polished specimens are etched with Keller's reagent (1% HF + 1.5% HCl + 2.5% HNO_3 + 95% H_2O). Microstructures of samples are examined by optical microscopy followed by SEM (TESCAN VEGA3 SBH).

The presence of various phases in chosen metal powders and sintered composite are obtained by employing X-Ray diffractometer (MiniFlex Rigaku) operated with radiation CuK_α. The hardness of the sintered composites is determined using Vickers hardness test.

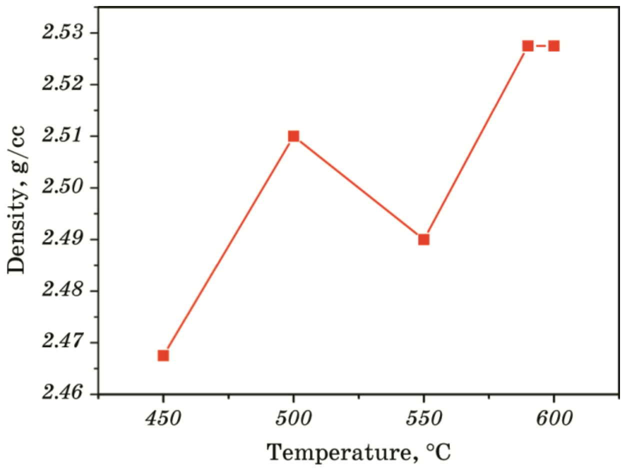
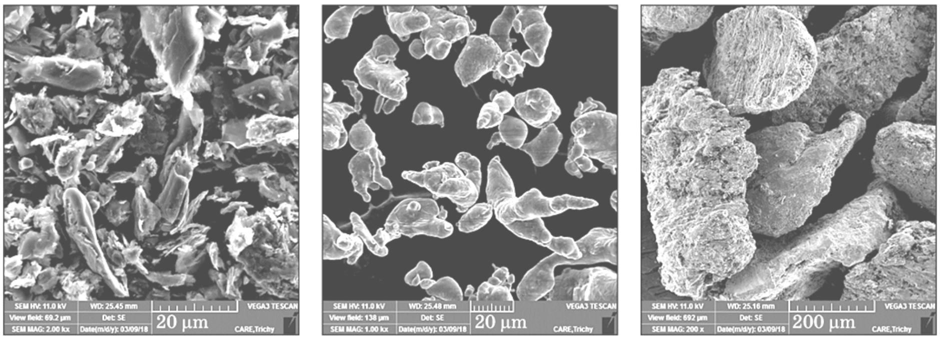


Fig. 2. Sintering temperature optimization with respect to density for Al–4Fe–5Gr sample.



a *b* *c*

Fig. 3. Morphology (SEM) of graphite (*a*), Al2024 (*b*), and Fe particles (*c*).

3. RESULTS AND DISCUSSION

The surface morphology of present metal powders is illustrated in Fig. 3. Graphite powder is in the form of the flakes of sizes up to 7.6 µm. Al2024 powder is mostly ellipsoidal, elongated particles of sizes up to15 µm. A more massive morphology is observed for the Fe powder, with a particle size between 214 µm.

The experimental density of the sintered hybrid composites is compared with theoretical density in Table 3 and 4. It shows that high densification is achieved in Al hybrid composite than Al2024 hybrid composite. The porosity of Al and Al2024 composites are compared in Fig.

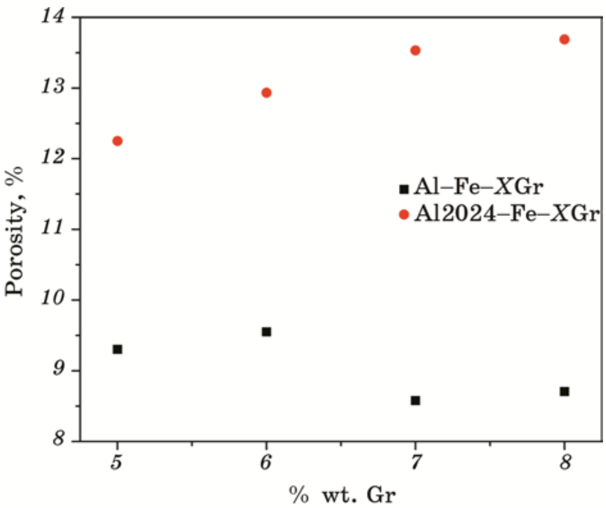


Fig. 4. Dependences of porosity of Al and Al2024 hybrid composites on graphite content.

TABLE 5. Vickers hardness of Al and Al2024 hybrid composites.

No.	% wt. of Graphite	Hardness, HV	
		Al composite	Al2024 composite
1	5	122.9	138.0
2	6	125.6	141.3
3	7	127.4	144.7
4	8	128.3	146.2

4. In the case of Al2024 hybrid composite, porosity increases with respect to graphite content. On the other hand, in Al hybrid composite graphite content with 7 and 8% wt. have lower porosity than 5 and 6% wt. The effect of graphite reinforcement on the hardness of compacted Al/A2024–Fe composite is observed in Table 5. The hardness value of each test specimen is an average of three test measurements. It shows that increases in the graphite content make increase the hardness value monotonously. In fact, as the graphite content increased from 5 to 8% in Al/Al2024–Fe–Gr the hardness increases by about 4.4 and 5.9%, respectively. As expected, the Al2024 hybrid composites have higher hardness compared to Al hybrid composites.

The XRD patterns corresponding to Al–4Fe–*X*Gr and A2024–4Fe–*X*Gr are shown in Fig. 5. It shows that in Al hybrid composite has no formation intermediate phase like aluminium carbide or cementite. It indicates only three simple phases such as f.c.c., b.c.c. and layered graphite structures are present in the composite. Garibay-Feblesh *et al.* [7] obtained binary intermediate phases of Al–Fe, Fe–C and Al–Gr system by mechanical alloying process. The XRD pattern of sintered Al2024–4Fe–*X*Gr composite shows that formation of new phase such

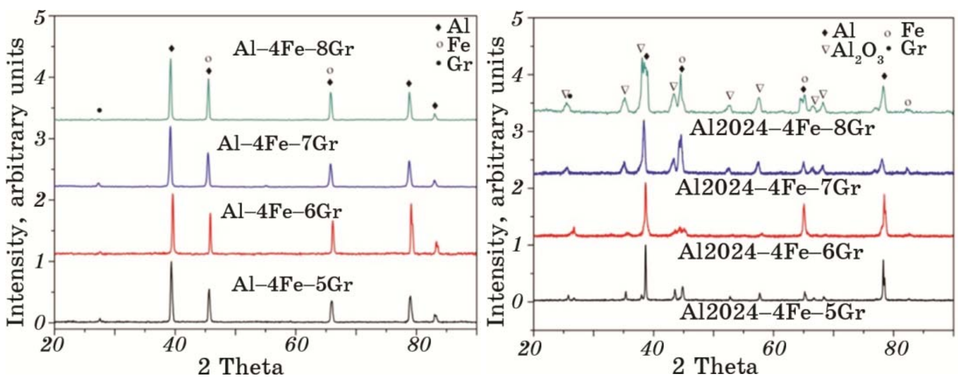
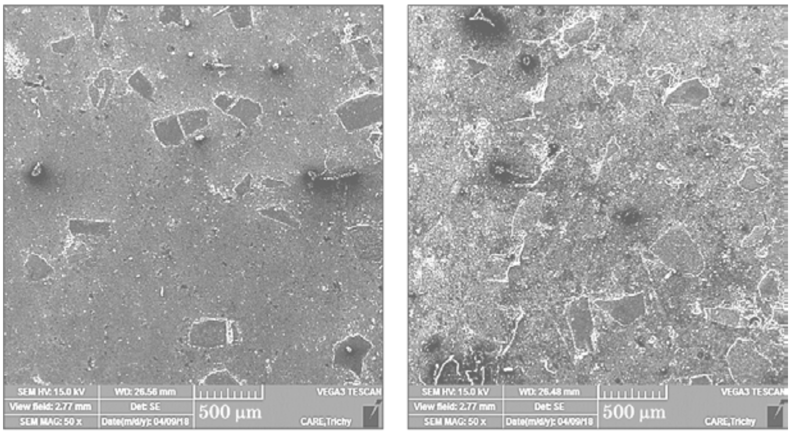


Fig. 5. XRD patterns of Al (left) and Al2024 (right) hybrid composites.



a *b*

Fig. 6. SEM micrographs of Al–4Fe–5Gr (left) and Al2024–4Fe–7Gr (right) composites with the magnification of ×50.

as aluminium oxide (Al_2O_3) formed in 5, 7, and 8% wt. graphite specimens. The formation of oxide does not affect the hardness property. However, oxide formation adversely affects the plasticity of the composite. The microstructures of Al–Fe–5Gr and Al2024–4Fe–7Gr composites are shown at ×50 magnification in Fig. 6. They show uniform distributions of Fe and Gr particles. The iron particles distinguish in microstructure due to their sizes. At the interface of Al2024 and Fe, oxide formation is observed in microstructure of Al2024–4Fe–7Gr alloy.

4. CONCLUSIONS

In the present work, the hybrid composite Al/Al2024–Fe–*X*Gr ($X = 5$, 6, 7, 8% wt.) was successfully made by the powder metallurgy process. Presence of various phases of matrix, reinforcements and hybrid composite are identified using XRD. The equilibrium phases of binary systems are not formed. As expected, Al2024 hybrid composite have high density and hardness compared to Al hybrid one. The Al2024 alloy undergoes oxidation much faster than Al alloy. The addition of graphite raises the hardness of both the composites. The effect of graphite on a wear and an electrical conductivity of same hybrid composites require further study.

REFERENCES

1. H. Ye. Chu and J. F. Lin, *Wear*, **239**, No. 1: 126 (2000).

2. M. Vogelsang, R. J. Arsenault, and R. M. Fisher, *Metallurgical Transactions A*, **17**, No. 3: 379 (1986).
3. B. C. Pai, S. Ray, K. V. Prabhakar, and P. K. Rohatgi, *Materials Science and Engineering*, **24**, No. 1: 31 (1976).
4. A. Sato and R. Mehrabian, *Metallurgical Transactions B*, **7**, No. 3: 443 (1976).
5. S. Mohan and S. Srivastava, *Tribology Letters*, **22**, No. 1: 45 (2006).
6. H.-Z. Kang and C.-T Hu, *Materials Chemistry and Physics*, **88**, Nos. 2–3: 264 (2004).
7. V. Garibay-Febles, H. A. Calderon, F. C. Robles-Hernández, M. Umemoto, K. Masuyama, and J. G. Cabacas-Moreno, *Materials and Manufacturing Processes*, **15**, No. 4: 547 (2000).