COMPRESSIVE PROPERTIES OF INSITU ($Al_3Zr+Al_2O_3$)/2024AL COMPOSITES WITH A NETWORK REINFORCEMENT ARCHITECTURE

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Abstract

In the present work hybrid, aluminium oxide (Al_2O_3) and zirconium tri-aluminide (Al_3Zr) reinforced 2024Al aluminium matrix composites with a network reinforcement architecture were successfully fabricated. In order to fabricate the insitu composite, techniques such as ball milling and powder metallurgy were used. The reinforcements were in situ synthesized using reaction hot pressing of the aluminium and ZrO_2 system. The dispersion of the reinforcements in a network fashion contributed to the effective strengthening of the 2024Al matrix. The composite with a network microstructure showed enhanced compressive properties when compared to the unreinforced Al alloy, ZrO_2/2024Al composite as well as the ($Al_3Zr+Al_2O_3$)/2024Al composite with a random dispersion of reinforcements.

1. Introduction

Discontinuously reinforced aluminium metal matrix composites (AMMCs) have been used widely in the fields of aerospace, transportation and power transmission modulus [1]. Particle reinforcements such as silicon carbide [2], and Al_2O_3 [3] for instance, have been widely used because they are relatively inexpensive commercial abrasives, that can offer good wear resistance as well as high specific stiffness. Furthermore, transition metal tri-aluminides such as Al_3Zr and Al_3Ti have received considerable attention in the past few decades due to their special characteristics, such as low density, good thermal conductivity, superior thermal stability, good machinability and easier consolidation [4-9]. However these trialuminides are brittle at room temperatures resulting in their limited applications.

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In order to fully utilize the potential of brittle reinforcemets in a metal matrix, Huang et al, have reported the successful fabrication of composites with network microstructures [10-12]. Moreover, an aluminium composite,with a network microstructure, reinforced with Al_2O_3 and Al_3Zr particles has also displayed enhanced tensile properties and hardness, when compared to a similar composite with a random didtribution of reinforcements[13]. Habibi et al, have reported the fabrication of hierarchical magnesium composites using hybrid microwave sintering. The composites consisted of a magnesium matrix reinforced with a pure aluminium matrix containing Al_2O_3 particles of different length scales (from micrometer to nanometer size). The network structure of the composite remarkably affected the composites tensile properties[14, 15].

In the past, investigations on the mechanical properties of AMMCs have focused mainly on the determination of its tensile characteristics. The performance of these materials under compressive loading has received only minor attention, in spite of the fact that these materials have great potential in fields such as aviation and automotive components (e.g., for engine pistons), where knowledge of the compressive characteristics is essential. In particular, materials with a network structure are being used in places where the loading is largely compressive in nature[16].

The following sections deal with the fabrication of a network structured $(Al_3Zr+Al_2O_3)$/2024Al composite and discusses its compressive properties. Effective comparisons have been made with with the monolithic 2024 Al alloy, a ZrO_2/2024Al composite and a $(Al_3Zr+Al_2O_3)$/2024Al composite with a random distribution of reinforcements.

2. Materials and methods

2.1. Materials

Spherical 2024 Al powders with an elemental composition (in wt. %) of Cu-4.5, Mg-1.14, Si-0.5, Fe-0.3, Mn-0.8, Zn-0.1 and the balance Al, as shown in Fig.1(a) were used.The size of the 2024Al powders ranged form 50 to 150 µm. ZrO_2 powders with an average size of (0.5 -0.8µm), as shown in Fig.1(b) was used.

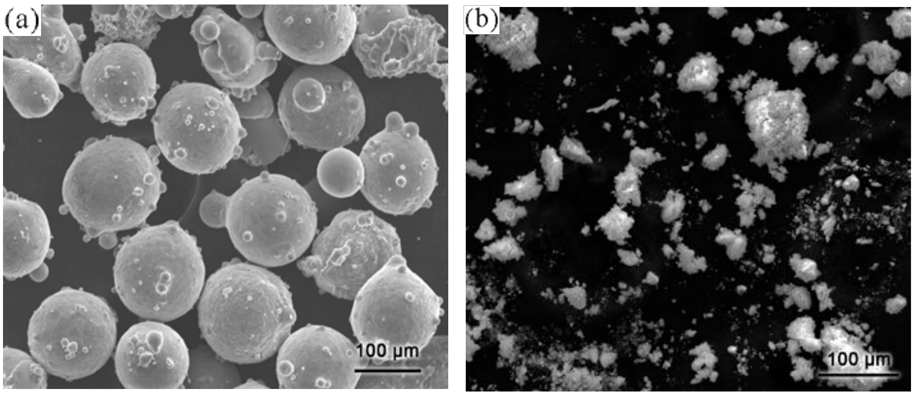

Figure 1. Raw materials (a)2024Al and (b)ZrO_2.

2.2. Fabrication of composites

The raw materials were blended, in order to get 10 vol.% of reinforcements, according to the reaction in Eq.(1) as shown below.

$$Al+ZrO_2 \rightarrow Al_3Zr+Al_2O_3 \quad (1)$$

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In order to attain a network microstructure low energy ball milling was used, with a ball to material ratio of 5:1,speed of 200 rpm and a milling time of 2 hours. Low energy was used in order to retain the sphericity of the 2024Al powders. As a result of using low energy the ZrO_2 parties were evenly distributed on the surface of the 2024Al powders. For comparison sake, the same powders were also milled with high energy - 300 rpm, 10 hours - in order to fabricate a composite with a homogeneous microstructure. The milled powders are shown in Fig.2(a) and (b).

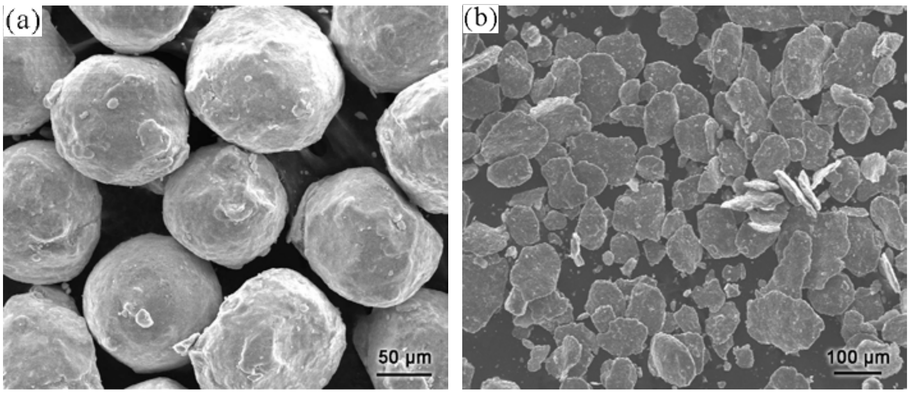

Figure 2. Ball milled 2024Al and ZrO_2 (a) at low energy and (b) high energy

The milled raw materials were transferred to a graphite mould and reaction sintering was carried out. The temperature of the furnace was raised to 570˚C and a pressure of 25MPa was applied for 30 minutes to attain a dense compact. This procedure ensured a good bonding between the 2024Al and ZrO_2 powders.At this point a ZrO_2/2024Al composite was attained. The temperature was then raised to 850˚C, which is the desired reaction temperature between Al and ZrO_2 as in Eq.(1), and held at 60 minutes to ensure complete reaction to take place. Subsequently, a pressure of 25MPa was reapplied during cooling at 600˚C for 30 minutes to effectively compact the reacted components. The composite with a homogeneous distribution of reinforcements was also fabricated in this manner. For meaningful comparison monolithic 2024Al powders were also sintered at 570˚C under a pressure of 25MPa for one hour. The sintering procedures were carried out under a high vacuum of 10-2 Pa and a heating rate of 10˚C/min.

2.3. Microstructural examination and testing

Scanning electron microscopy (SEM, Quanta 200FEG) along with energy-dispersive x-ray spectroscopy (EDX) were used to perform microstructural examinations. Compressive tests were carried out using an Instron-5569 universal testing machine at a constant crosshead speed of 0.5 mm/min. Compressive specimens had dimensions of ϕ 8mm × 12 mm. A total of five samples were tested for each material.

3. Results and discussion

Fig.3(a) shows the microstructure of the as-sintered 10vol.% composite with a network reinforcement architecture. It can be seen that there is a reinforcement rich network of particles surrounding the reinforcement lean matrix regions. The reinforcements rich network mainly consists of Al_3Zr and Al_2O_3 nano-particles. The Al_3Zr particles vary from 5-10μm. It should be noted that the reinforcemt particles do not form a impenetrable network, rather the network of particles allows interconnectivity of the matrix regions. Thus it can also be said the particles form a quasi-continuous network. Fig 3(b) reveals the microstructure of the as-sintered 10 vol. % composite with a network reinforcement architecture after compression.It can be clearly seen that there is significant deformation in the matrix

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regions. However, the network structure of the composite still exists. The matrix regions are elongated in the direction perpendicular to the direction of compression.

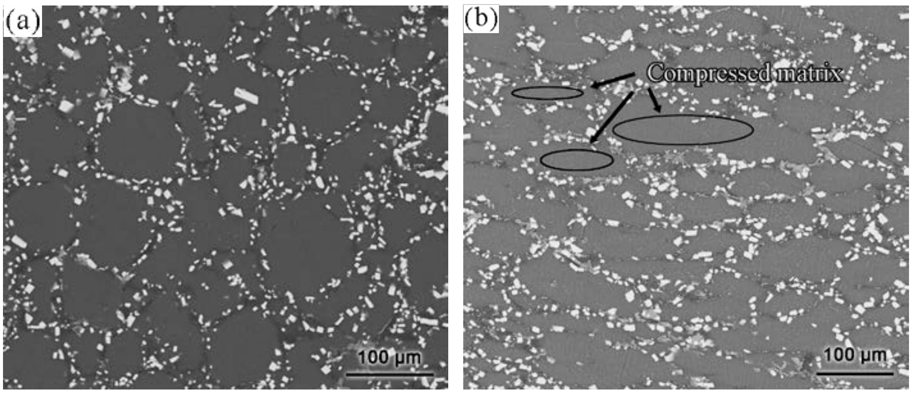

Figure 3. Microstructure of the (Al_3Zr+Al_2O_3)/2024Al network structured composite (a) as-sintered and (b) post compression

Fig.4(a) shows the compressive stress-strain curves of the unreinforced 2024Al alloy and the various other composites. The compressive strength of the network structured composite is significantly higher when compared to the unreinforced 2024Al alloy and the other composites. Fig.4(b) revels the compressive yield strength of the unreinforced 2024Al alloy and the composites. It can be clearly observed that the compressive yield strength of the composite with the network distribution is higher than the other three materials. The increase in strength must be attributed to the network structure itself, because both the other composites under comparison, are similar in every other way except for this microstructural difference. It is suggested that, as the compressive load increases the skeletal network – which consists of a high volume fraction of Al_3Zr and Al_2O_3 particles – bears the load.Once the stress reaches a critical level, cracks emerge and progress in the reinforcement particles and the matrix until complete failure occurs.

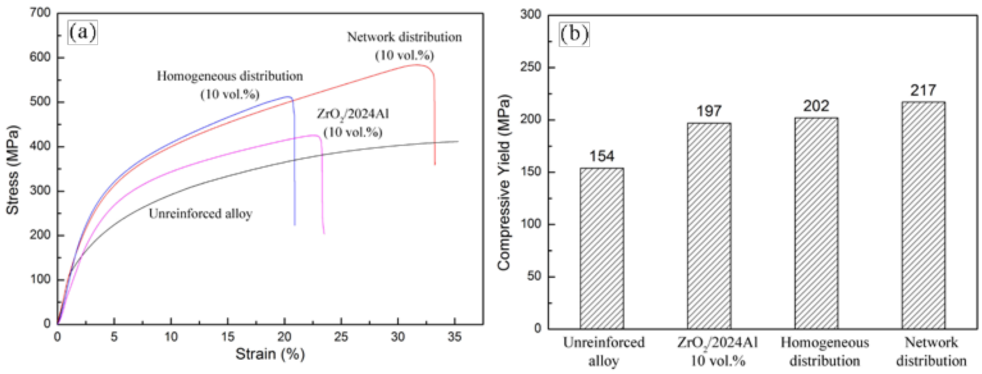

Figure 4 Compressive porpoerties of the unreinforced 2024Al alloy, 10 vol.% ZrO_2/Al, as-sintered (Al_3Zr+Al_2O_3)/2024Al homogeneous and network structured composite (a) stress-strain cureves and (b) compressive yield strength

Fig.5 shows the failure profile of the (Al_3Zr+Al_2O_3)/2024Al network structured composite. The plastic deformation of matrix is effectively obstructed by the stronger reinforcement network, which is beneficial to the comoressive yield strength of the composite. It can be noticed that as the loading is increased, cracks originate in the reinforcement particles and follow along the network, indicating that the network of particles absorb most of the compressive energy. Additionally, in the homogeneous composite(with a random dispersion of reinforcements) the crack probably follows a straight path, propogating through the regions containing agglomerated Al_3Zr particles.This form of failure has been widely documented in AMMCs with a random dispersion of reinforcements.

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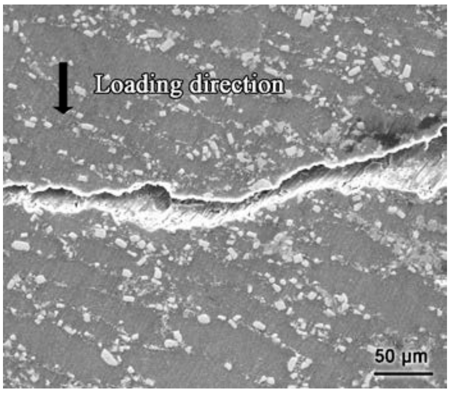

Figure 5 Compressive failure profile of the $(Al_3Zr+Al_2O_3)$/2024Al network structured composite

Fig.5 shows a photograph of the post compression profile of the monolithic 2024Al alloy, the composite with a homogeneous distribution and the network structured composite. As it can be seen, the network structured composite shows a uniform barreling profile, indicating the uniform deformation of the composite. However, in the homogeneous composite the barreling effect is not uniform revealing the inferior ductility of the composite. Moreover, multiple intersecting crack lines also indicate that failure of these composite originate at different points, leaving a badly damamged surdace.Hence in can be said that the network structure also plays a crucial role in determining the mode of failure in the composite.

Figure 6 Photographs of samples after compression test (a) Unreinforced 2024Al alloy (b) 10 vol.% homogeneous composite and (c) 10 vol.% network structured composite.

Conclusions

10 vol.% $(Al_3Zr+Al_2O_3)$/2024Al composites with a network distribution and random distribution of reinforcements were successfully fabricated using ball milling and reactive hot pressing. The composite with a network reinforcement architecture demonstrated superior compressive yield strength when compared to the monolothic 2024Al alloy, ZrO_2/2024Al composite, and the $(Al_3Zr+Al_2O_3)$/2024Al composite with a random dispersion of reinforcemets. The network structure in the composite played a key role in determining the failure mode of the $(Al_3Zr+Al_2O_3)$/2024Al composite.

Acknowledgments

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Excerpt from ISBN 978-3-00-053387-7

References

[1] L. Froyen, B. Verlinden, Aluminium matrix composites materials, TALAT, European Aluminium Association, 1994.

[2] A. Macke, B.F. Schultz, P.K. Rohatgi, N. Gupta, *Metal Matrix Composites for Automotive Applications*, John Wiley & Sons Ltd, 2013.

[3] B.F. Luan, N. Hansen, A. Godfrey, G.H. Wu, Q. Liu. High strength Al–Al_2O_{3p} composites: Optimization of extrusion parameters. *Materials & Design,* 32: 3810-3817, 2011.

[4] R.A.Varin. Intermetallic-reinforced light-metal matrix in-situ composites. *Metallurgical and Materials Transactions A,* 33A: 193-201, 2002.

[5] S.C. Ferreira, L.A. Rocha, E. Ariza, P.D. Sequeira, Y. Watanabe, J.C.S. Fernandes. Corrosion behaviour of Al/Al_3Ti and Al/Al_3Zr functionally graded materials produced by centrifugal solid-particle method: Influence of the intermetallics volume fraction. *Corrosion Science,* 53: 2058-2065, 2011.

[6] H. Zhu, J. Min, J. Li, Y. Ai, L. Ge, H. Wang. In situ fabrication of (α-Al_2O_3+Al_3Zr)/Al composites in an Al–ZrO_2 system. *Composites Science and Technology,* 70: 2183-2189, 2010.

[7] G. Ashok Kumar, I. Dinaharan, S.J. Vijay, N. Murugan. Friction stir processing of intermetallic particulate reinforced aluminum matrix composite. *Advanced Materials Letters,* 4: 230-234, 2013.

[8] Z. Jinxu, H. Gengxiang, W. Jiansheng, X. Weixin. Electron structure and bonding characteristics of Al_3Ti intermetallic alloys. *Journal of Materials Science Letters,* 19: 1685-1686, 2000.

[9] Y.V. Milman, D.B. Miracle, S.I. Chugunova, I.V. Voskoboinik, N.P. Korzhova, T.N. Legkaya, Y.N. Podrezov. Mechanical behaviour of Al_3Ti intermetallic and L12 phases on its basis. *Intermetallics,* 9: 839-845, 2001.

[10] L.J. Huang, L. Geng, A.B. Li, F.Y. Yang, H.X. Peng. In situ TiBw/Ti–6Al–4V composites with novel reinforcement architecture fabricated by reaction hot pressing. *Scripta Materialia,* 60: 996-999, 2009.

[11] L.J. Huang, L. Geng, H.X. Peng. In situ (TiBw+TiCp)/Ti6Al4V composites with a network reinforcement distribution. *Materials Science and Engineering: A,* 527: 6723-6727, 2010.

[12] L.J. Huang, S. Wang, L. Geng, B. Kaveendran, H.X. Peng. Low volume fraction in situ (Ti_5Si_3+Ti_2C)/Ti hybrid composites with network microstructure fabricated by reaction hot pressing of Ti–SiC system. *Composites Science and Technology,* 82: 23-28, 2013.

[13] B. Kaveendran, G.S. Wang, L.J. Huang, L. Geng, Y. Luo, H.X. Peng. In situ (Al_3Zr_p+Al_2O_{3np})/2024Al metal matrix composite with controlled reinforcement architecture fabricated by reaction hot pressing. *Materials Science and Engineering: A,* 583: 89-95, 2013.

[14] Meisam Kouhi Habibi, Shailendra P. Joshi, M. Gupta. Development of hierarchical magnesium composites using hybrid microwave sintering. *Journal of Microwave Power and Electromagnetic Energy,* 45: 112-120, 2011.

[15] M.K. Habibi, M. Gupta, S.P. Joshi. Size-effects in textural strengthening of hierarchical magnesium nano-composites. *Materials Science and Engineering: A*, 556: 855-863, 2012.

[16] P. Fratzl, R. Weinkamer. Nature’s hierarchical materials. *Progress in Materials Science*, 52: 1263-1334, 2007.

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