ISBN: 978-1-948012-17-1

Ethics and Information Technology (ETIT)

DOI: <http://doi.org/10.26480/etit.02.2020.147.150>

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STUDY ON VARIOUS PROPERTIES OF FABRICATED CRYSTALLINE SILICA-REINFORCED ALUMINIUM METAL MATRIX COMPOSITES

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ARTICLE DETAILS

Article History:

Received 25 October 2020

Accepted 26 November 2020

Available online 03 December 2020

ABSTRACT

Authors have taken an attempt to fabricate aluminium metal matrix composites with crystalline silica reinforcement where volume percentage (vol. %) of reinforcement is varied from 2.0 % to 30.3 %. Crystalline silica- reinforced aluminium metal matrix composites have fabricated through conventional powder metallurgy technique with varying sintering temperatures. Optimized fabricating environment has identified from the property studied on the fabricated metals. Elemental compositions have identified with energy dispersive x-ray spectroscopy (EDX), surface morphology has studied via optical microscopy (OM) and scanning electron microscopy (SEM). Deviation from theoretically and actually achieved properties have found out and reported.

KEYWORDS

Crystalline silica- reinforced Aluminium Composites, Powder Metallurgy, Surface Morphology, Density, Porosity, Hardness, Young Modulus, Tensile strength.

1. INTRODUCTION

Continuous efforts have observed among the materials engineers towards invention of new materials that might be utilized in various engineering and allied fields of technology. Composites are one of the reliable source to meet such demands on the modern industries as composite offers greater strength, stiffness and comparatively low density than conventional metal and alloys (Bharath et al., 2012; Kleme et al., 2006; Toptan et al., 2009; Chawla and Chawla, 2006). Powder metallurgy is an art or technology by which lightweight materials can be fabricated cost effectively with exact size and dimensions as per requirement.

Aluminium is most available metals on earth and is widely used in different sectors of electrical/ electronics industries, transport applications including aerospace, aeronautics, automobile applications for its conductivity, excellent casting abilities, corrosion resistant, low thermal expansion, wear resistant, moreover low density (Prasad and Asthana, 2004; Hesabi et al., 2006; Tong and Ghosh, 2001; Magesh et al., 2014; Hamouda et al., 2007). However, low strength and low melting point converge the applications of pure aluminium (Usman et al., 2014; Wakeel, 2017; Dixit, 2018; and many more) in limited fields. These problems can be shorted out with reinforcing suitable ceramic particles into aluminium matrix; SiC, Al₂O₃, TiC, Ti-Aluminide, B₄C, Si are very commonly used reinforcement for aluminium matrix (Bharath et al., 2012; Toptan et al., 2009; Hesabi et al., 2006; Tong and Ghosh, 2001; Magesh et al., 2014; Hamouda et al., 2007; Usman et al., 2014; Tong and Ghosh, 2001; Hembrom et al., 2016; Huo and Woo, 2006; Shi, 2001; and many more). Until very limited work has observed towards fabricating crystalline silica- reinforced aluminium metal matrix composites and the evaluation and/ or computation of various properties are scarce.

This study based on the fabrication of crystalline silica- reinforced aluminium metal matrix composites and an exploratory comparative study has carried out between various theoretical and obtained properties of these fabricated metals.

2. EXPERIMENTAL PROCEDURE

The procedures for this study have described below.

2.1 Fabrication of crystalline silica- reinforced aluminium metal matrix composites

Crystalline silica- reinforced aluminium metal matrix composites have fabricated maintaining the steps of milling and mixing the constituent materials (mesh size ~200 µm), then pressing and sintering has carried out simultaneously into hot press ('Nascor technologies Pvt. Ltd,' Howrah, India) for an hour. Sintering has carried out separately at 500°C, 550°C and 600°C for finding out optimized sintering environment. Mentioned that the used crystalline silica has extracted from natural sand maintaining temperature 1150°C, demonstrated in previous study (Debnath and Pramanick, 2016). Debnath and Pramanick, March- April 2016, reported that any reaction has not taken place between aluminium matrix and silica- reinforcement for this sintering environment.

2.2 Testing and characterization

Surface morphology has studied after routine polishing the fabricated metals with 'LEICA' Optical Microscopy (model no. 'DM-2700M') and SEM (model 'JSM 6360').

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	International Conference on Contemporary Issues in Computing (ICCIC-2020) - Virtual IETE Sector V, Salt Lake, Kolkata From 25th-26th July 2020	Website: www.intelcomp-design.com	DOI: 10.26480/etit.02.2020.147.150

Micro-hardness has taken utilizing 'Leco Micro Hardness tester' (model 'LM248SAT'), applying 100 gf loads for 10 sec dwell time. Hardness has measured in different positions for each fabricated metal and finally, average value has considered for achieving more accuracy.

3. RESULTS AND DISCUSSION

Obtained results and corresponding discussions have elaborated below.

3.1 Surface Morphology

Figure 1: Microstructure (optical) for (a) 2.00 % (b) 10.14 %, (c) 15.19 %, (d) 30.30 % (based on vol. %) crystalline silica- reinforced aluminium metal matrix composites at 20X magnification

Figure 2: Surface morphology (SEM) of (a) 20.24 %, (b) 30.30 % (based on vol. %) crystalline silica- reinforced aluminium metal matrix composites

Surface morphology based on microstructure has shown in fig. 1 for various compositions of crystalline silica- reinforced aluminium metal matrix composites. Crystalline silica particulates have distributed systematically into soft aluminium matrix. Well distribution of crystalline silica particulates have also observed on SEM image shown in fig. 2.

3.2 Mapping on SEM/ EDX

Figure 3: Mapping on SEM/ EDX, (a) electron image for 10.14 % (based on vol. %) crystalline silica- reinforced aluminium metal matrix composite, (b) distribution of aluminium, (c) EDX analysis

Mapping on SEM/ EDX has conducted not only identifying the elemental composition and distribution of constituent elements on the surface after sintering but also for understanding whether any contamination or reaction has occurred or not. Fig. 3(a) shows the sintered surface, fig. 3(b) shows the distribution of aluminium on this surface using green colour and fig. 3(c) shows the overall elemental composition for 10.14 % (based on vol. %) crystalline silica- reinforced aluminium metal matrix composite. From EDX analysis, it has clear that any contamination has not taken place during fabrication.

3.3 Study on physical properties

3.3.1 Density

Figure 4: Variation of theoretical and actual densities

Figure 4 shows the sintered densities of crystalline silica- reinforced aluminium metal matrix composites in both theoretical and actual prospective for the sample fabricated at 600°C. Actual densities have deviated slightly than theoretical value shown in fig. 4. The probable reason of this little deviation is due to the presence of voids as typical variation of porosity is found out 0.217 % (for sintered aluminium) (Debnath and Pramanick, March- April 2016) to maximum 0.286 % (for 30.30 % crystalline silica- aluminium composite) for the sample sintered at 600°C.

3.3.2 Apparent Porosity

Figure 5: Variation of apparent porosity with sintering temperatures

Figure 5 shows the variation of porosity with both sintering temperature and crystalline silica reinforcement. Tendency of pore formation has increased with addition of crystalline silica reinforcement and observed least amount of porosity for the sample fabricated at 600°C.

3.4 Study on mechanical properties

3.4.1 Variation of UTS with hardness

The variation of ultimate tensile strength (UTS) with hardness has noted in table 1. Observed that hardness, hence, UTS (Zhang and Zhang, 2011; Gaško and Rosenberg, 2011), has changed with both the reinforcements and sintering temperature.

Variation of UTS because of change in hardness for the sample sintered at 600°C (Debnath and Pramanick, March- April 2016) has plotted in fig. 6. It has observed that UTS has improved 1.9 times after addition of 30.30 vol. % crystalline silica- reinforcement into aluminium matrix for the sample fabricated at 600°C.

Table 1: Variation of hardness and ultimate tensile strength (UTS)

Composition	Fabricated at 500°C		Fabricated at 550°C		Fabricated at 600°C	
	Micro-hardness in MPa	UTS in MPa	Micro-hardness in MPa	UTS in MPa	Micro-hardness in MPa	UTS in MPa
Pure sintered aluminium	269.60	89.87	293.20	97.73	386.40 (Debnath and Pramanick, March-April 2016)	128.80
2 % crystalline silica- reinforced aluminium composite	273.00	91.00	296.30	98.77	389.00	129.67
5.07 % crystalline silica- reinforced aluminium	306.00	102.00	318.90	106.30	537.40	179.13
10.14 % crystalline silica- reinforced aluminium	375.50	125.17	431.70	143.90	587.69	195.89
15.19 % crystalline silica- reinforced aluminium	443.30	147.77	472.40	157.47	601.00	200.33
20.24 % crystalline silica- reinforced aluminium	488.40	162.80	520.80	173.60	641.90	213.96
30.30 % crystalline silica- reinforced aluminium	500.60	166.87	526.60	175.53	749.80	249.93

Figure 6: Variation UTS with reinforcement

3.4.2 Young modulus and tensile strength

Young modulus and tensile strength of fabricated composites can be computed theoretically by rules of mixture. Young modulus has taken as 69 GPa and 66.3 GPa respectively for aluminium and crystalline silica respectively (Prasad and Asthana, 2004; Dixit, 2018; Kumar et al., 2009; Butt et al., 2016; Imran and Sadik, 2016; Das et al., 2014; and many more). Variation of young modulus and tensile strength with crystalline silica reinforcement into aluminium matrix have demonstrated in table 2. For calculating tensile strength, tensile strength of aluminium and crystalline silica have considered 90 MPa and 80 MPa respectively from standard literatures (Prasad and Asthana, 2004; Dixit, 2018; Kumar et al., 2009; Butt et al., 2016; Imran and Sadik, 2016; Das et al., 2014; and many more). The composites fabricated at 600°C are perhaps shows these values due to the presence of negligible amount of pores or void spaces.

Table 2: Young modulus and tensile strength for crystalline silica-reinforced aluminium composites

Composition	Young modulus in GPa	Tensile strength in MPa
2 % crystalline silica- reinforced aluminium composite	68.946	89.800
5.07 % crystalline silica- reinforced aluminium	68.863	89.493
10.14 % crystalline silica- reinforced aluminium	68.726	88.986
15.19 % crystalline silica- reinforced aluminium	68.589	88.481
20.24 % crystalline silica- reinforced aluminium	68.450	87.972
30.30 % crystalline silica- reinforced aluminium	68.170	86.960

4. CONCLUSIONS

The significant conclusions based on the study of crystalline silica-reinforced aluminium metal matrix composites are as follows:

- Crystalline silica- reinforced aluminium metal matrix composites have fabricated successfully though powder metallurgy technique with significant reduction on weight.
- The composites fabricated utilising 600°C sintering temperatures have all the favourable properties and theoretical considerations can be applied on these composites. Beyond the improvement of sintering temperature than 600°C will results the melting of aluminium under hot pressing.
- Crystalline silica reinforcement is able to significant improvement of hardness with slight compromising both the modulus of elasticity and strength.

Appendix A

The formulas, which have used in computation, described in this appendix section.

A.1. Theoretical relation between hardness and strength

$$H_v = 3 \sigma_{UTS} \quad (1)$$

Where, H_v has used for representing the hardness and σ_{UTS} is the ultimate tensile strength.

A.2. Rule of mixture for particulate reinforced composites

$$d_c = d_f V_f + d_m V_m \quad (2)$$

$$E_c = E_m V_m + E_f V_f \quad (3)$$

$$\sigma_c = \sigma_m V_m + \sigma_f V_f \quad (4)$$

Where, d represents the density, σ is representing stress, E is being modulus of elasticity, V is volume fraction ($V_m + V_f = 1$) and the notation of 'c', 'm' and 'f' are being used for representing the composite, matrix and reinforcement respectively.

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