

# Development and Evaluation of Various Properties of Crystalline Silica-Aluminium Metal Based Composites

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**Abstract**— Aluminium based metal composites have been developed due to its superior properties and performance. The aim of this study is to develop aluminium metal based composites with crystalline silica as reinforcement. Aluminium metal based composites with 5, 10, 15, 20, 30 Wt. % crystalline silica were developed through powder metallurgy techniques and characterized by XRD, EDX, Microstructure, and SEM. Physical properties like density, porosity and mechanical property like hardness have been observed. It has been seen that addition of 30 Wt. % crystalline silica was able to increase the hardness nearly two times than pure aluminium. It has been observed density decreases while both apparent porosity and hardness increases with silica content. This study also involves the effect of adding silica particulates on corrosion behavior of Silica-Aluminium metal based composite in 3.5% NaCl solution at room temperature using polarization method at scan rate 3 mV/sec. The result obtained from the potentiodynamic polarization test shows that corrosion rate decreases due to increase of crystalline silica particulate on aluminium matrix.

**Keywords**— Aluminium matrix, Crystalline silica particulate, Powder metallurgy, XRD, EDX, Microstructure, SEM, Density, Porosity, Micro hardness, Corrosion.

## INTRODUCTION

Modern technology requires materials with unusual combination of properties that could not be met by conventional metal alloys, ceramic and polymeric materials. In practice, metal matrix composites are preferred for greater strength, stiffness and low weight compared to metal and alloys [1-4] and can withstand higher temperature than polymer matrix composites. Metal matrix also exhibit good fracture toughness. In metal matrix composite (MMC), fibrous or particulate phase is distributed in metal matrix. Metal matrix composite reinforced with ceramic particulate have shown improved sliding wear resistance [5, 6].

Aluminium based metal composite is preferable and widely used as a substitute material in transport sector especially in aerospace, aeronautics and automobile applications for making engine parts due to its good casting abilities, high corrosion resistance, low thermal expansion, wear resistant, and low density [7-11].

On the other hands low strength and low melting point are the problems for using pure aluminium and its alloys [12]. These problems can be solved by reinforcing SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, SiC in whiskers or particulate form in aluminium matrix [12]. The reinforcing phase is selected depending on the application of developed material and compatibility between matrix and second phase. Load transfer capability between matrix and reinforcement depends on the matrix composition, the nature of the reinforcement, the fabrication method, and the sintering temperature of the composite. Strong interface protect crack propagation across both matrix and second phase. SiC, Al<sub>2</sub>O<sub>3</sub>, TiC, Ti-Aluminide, B<sub>4</sub>C, Si are the commonly used particulates for reinforcement on aluminium based metal matrix [7, 13-18] but the use of silica as reinforcement on pure aluminium matrix is rare.

This paper describes about the development methods of Silica-Aluminium metal based composite and various physical, mechanical, and also chemical property in various environment.

## EXPERIMENTAL PROCEDURE

### 2.1 Development of Silica-Aluminium Metal Based Composite by Powder Metallurgy Technique

The matrix material used in the present study was aluminium powder (99.7 %) and crystalline silica (SiO<sub>2</sub>) powder, obtained from natural sand. Crystalline silica was prepared with heating natural sand at 1150<sup>o</sup>C for one hour in muffle furnace at open atmosphere. Mixture of silica-aluminium powder with composition of 0%, 5%, 10%, 15%, 20%, and 30% crystalline silica (based on Wt. % of SiO<sub>2</sub>) were mixed in hand driven ceramic bowls with ceramic pressing hammer until very fine powder was produced, mesh size -200

$\mu\text{m}$ . Then the compact powder was pressed and sintered at  $600^{\circ}\text{C}$  for 1 hour duration using hot press. Figure 1 shows the step wise development of silica-aluminium metal matrix composite.

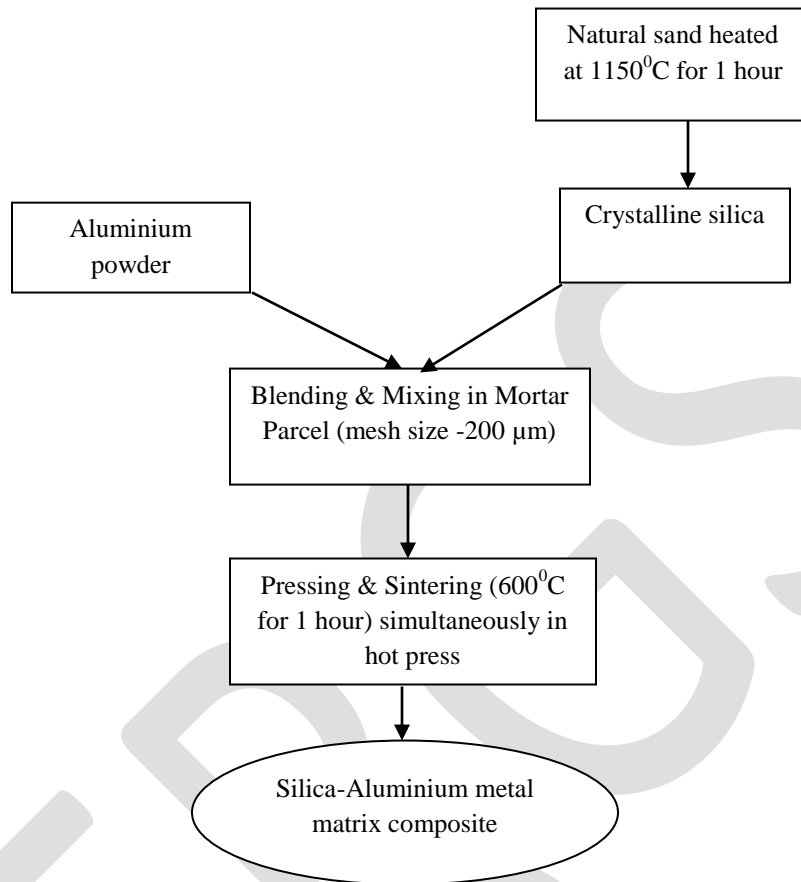


Fig. 1. Flowchart for development of crystalline silica-aluminium metal based composite

## 2.2 Testing and Characterization

### 2.2.1 XRD Analysis

X-ray diffraction (XRD) patterns were obtained for silica-aluminium composites using Rigaku Ultima III analytical diffractometer (with  $\text{Cu-K}\alpha$  radiation,  $\lambda = 1.54059 \text{ \AA}$ ) at 40 kV and 30 mA. Intensity (% abundance) data were recorded by the step-counting method (step 0.05 and a time per step of 0.6 second) between  $10^{\circ}$  and  $80^{\circ}$  ( $2\theta$ ) for each sample. Various phases were identified by comparing with standard JCPDS files.

### 2.2.2 Microstructure

For observing microstructure the surfaces were mirror polished by the emery paper 1/0 and 2/0 grade and then wheel cloth. After polishing, the samples were etched by Keller's solution and microstructures were observed at 20 X magnification by LEICA Optical Microscopy model no DM-2700M Image Analyzer.

### 2.2.4 SEM/EDX Analysis

SEM/EDX was carried out for each sample using JEOL MAKE SEM model JSM 6360, operated by PCSEM software.

### 2.2.5 Density and Apparent Porosity Measurement

Weight and dimension were measured for each sample to determine the density of the final composite product. Apparent Porosity was measured by the universal porosity measurement technique.

## 2.2.6 Micro-hardness

Micro-hardness survey was carried out on the same metallographic specimen of bead –on– plate sample at different positions by using 100 gf loads with 10 sec dwell time. The hardness was taken simultaneously in three different positions and finally averages them for more accuracy using Leco Micro Hardness tester (Model LM248SAT).

## 3. RESULTS AND DISCURSION

### 3.1 XRD Analysis

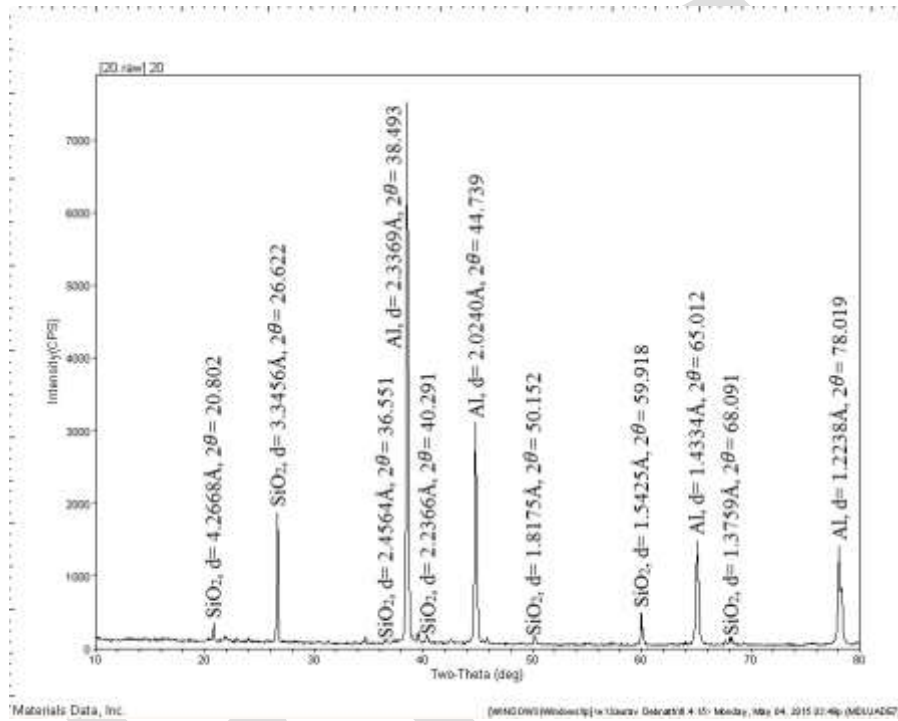


Fig. 2. XRD of 20 Wt. % crystalline silica-aluminium blended powder

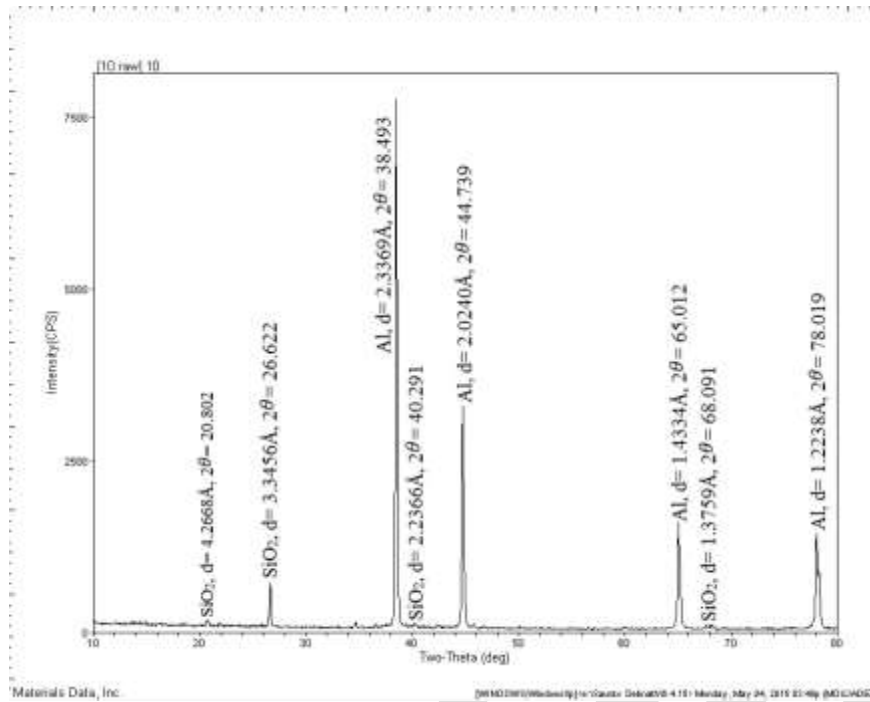


Fig. 3. XRD of 20 Wt. % crystalline silica-aluminium composite

XRD analysis before sintering was conducted for checking the purity of the crystalline silica- aluminium compact powder as crystalline silica was obtained from natural sand. Figure 2 and 3 shows the presence of only crystalline silica and aluminium before and after sintering.

### 3.2 Microstructure

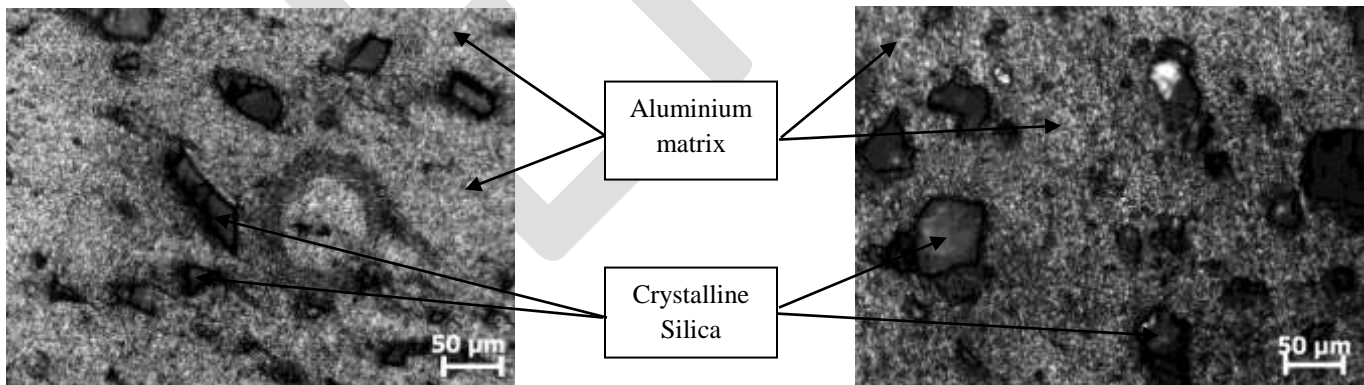
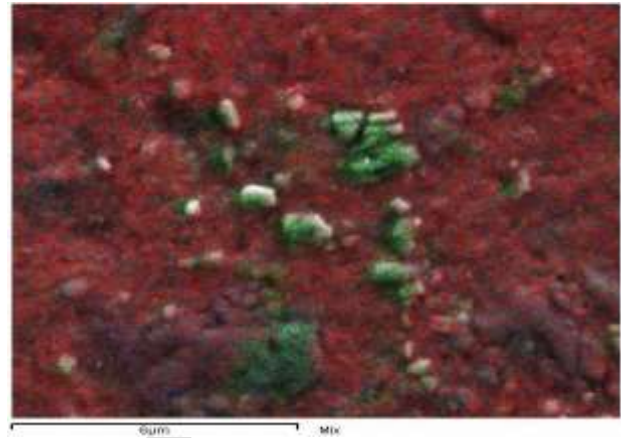
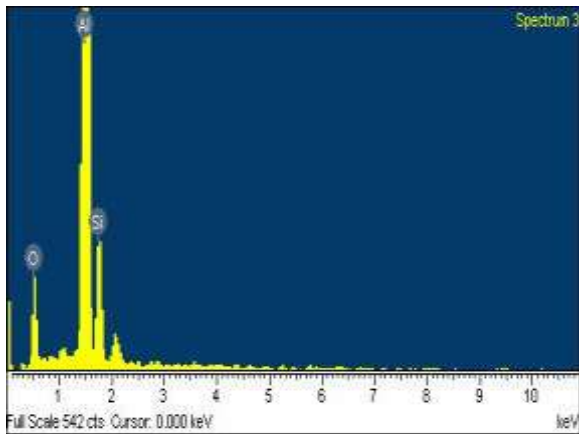


Fig. 4. Microstructure by optical microscopy at 20X magnification for (a) 5 Wt. % and (b) 10 Wt. % crystalline silica-aluminium composite

In figure 4, black portion indicates silica particles and white portion indicates aluminium matrix. Crystalline silica particulates are well distributed throughout entire aluminium matrix.

### 4.3 EDX Analysis



(a)

(b)

Fig. 5. EDX Analysis (a) EDX analysis (b) MAPPING on EDX

From EDX, there was 82.04 Wt. % Aluminium, shown by the highest peak in figure 5 (a). Corresponding mapping of EDX is shown in figure 5 (b) where red indicates aluminium (Al), green indicates silicon (Si) and white indicates oxygen (O). Actually, EDX analysis after sintering was done for known the elemental composition of the developed composite after sintering, precisely for understanding more clearly about the reaction between aluminium matrix and crystalline silica particulates. Result shows that there was no other element produced other than Si, O, and Al.

#### 4.4 SEM Analysis

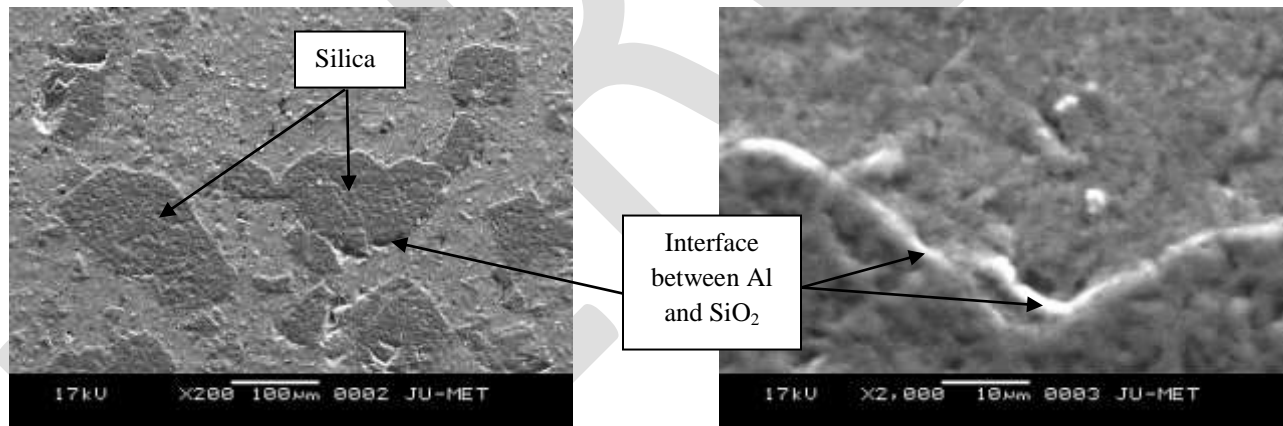


Fig. 6. SEM image of 20 Wt. % crystalline silica-aluminium composite (a) distributions of silica on aluminium matrix, (b) interface between silica particulates and aluminium matrix

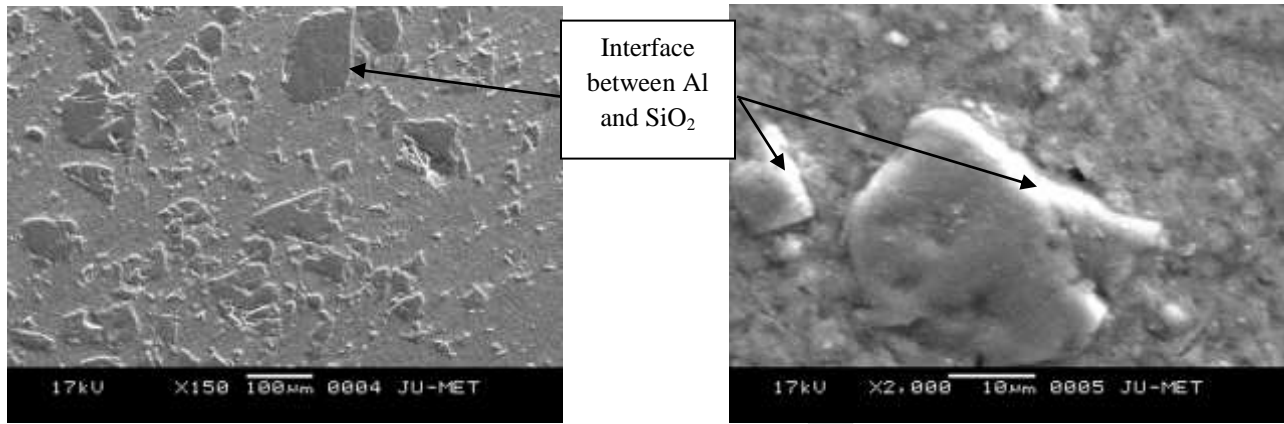


Fig. 7. SEM image of 20 Wt. % crystalline silica-aluminium composite (a) distributions of silica on aluminium matrix, (b) interface between silica particulates and aluminium matrix

SEM analysis was carried out to identify morphology, distribution of crystalline silica particulate in aluminium matrix and bonding quality between ceramic and metal matrix. Figure 6 (b) and 7 (b) shows the interface and bonding between aluminium matrix and crystalline silica particulate which indicates that crystalline silica particulate in aluminium matrix reduce the mobility of aluminium grain boundaries and better adhesion between matrix and reinforcement.

#### 4.5 Density Measurement

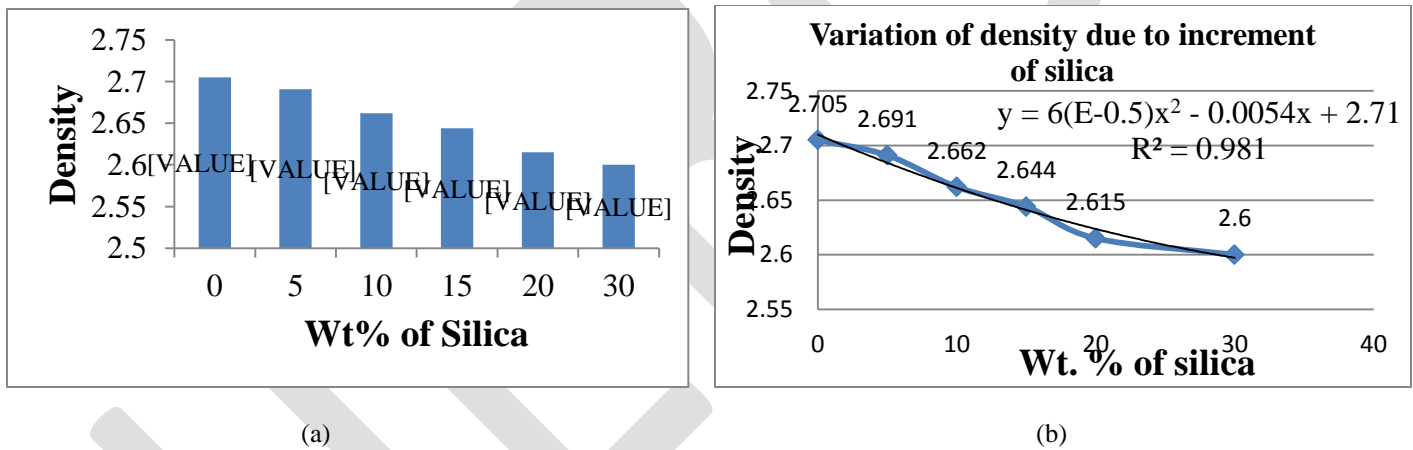


Fig. 8. Density- (a) individual density, (b) Variation of density due to increment of crystalline silica

Figure 8 shows that density, hence weight of the composite material, decreases with increment of crystalline silica particulates in aluminium matrix.

#### 4.6 Apparent Porosity

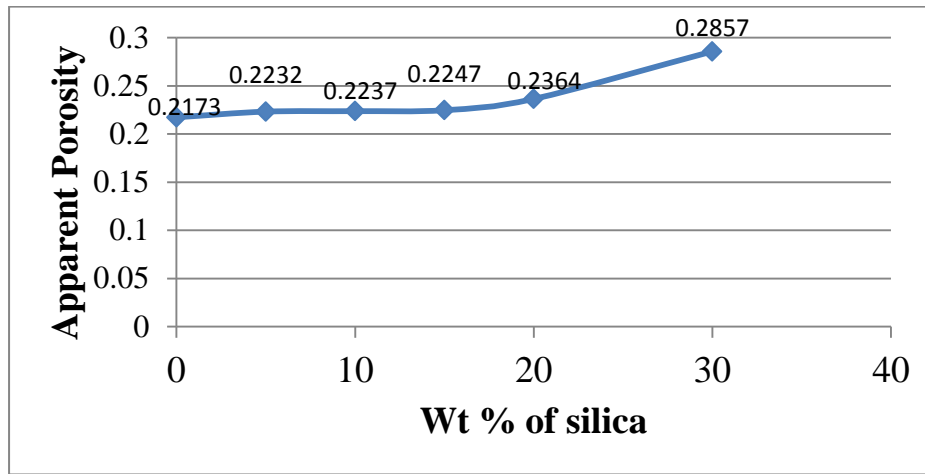


Fig. 9. Variation of apparent porosity due to increment of silica

Figure 9 implies that porosity is very low and vary only 0.2173% to 0.2857 % which is slightly increased due to increment of crystalline silica.

#### 4.7 Hardness

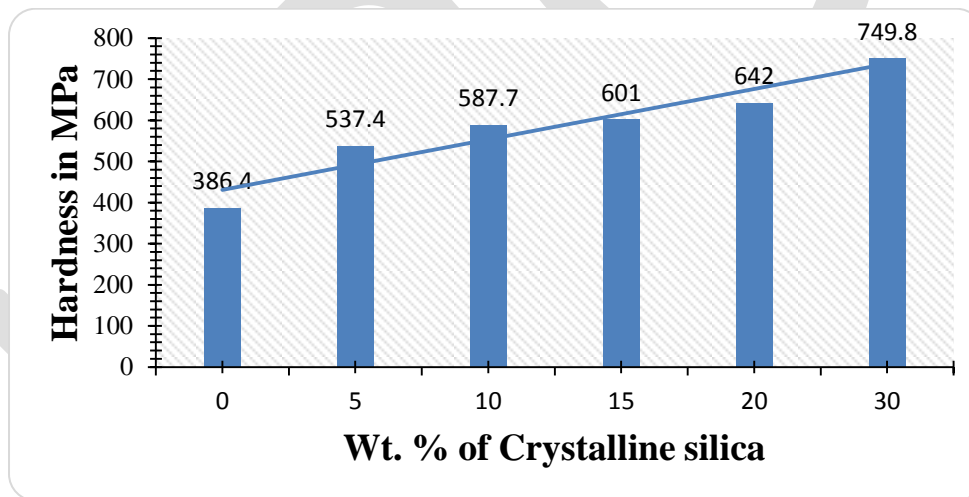


Fig.-10, Variation of hardness due to increment of crystalline silica

Figure 10 suggest that hardness values were increased gradually with increment of crystalline silica particulates in aluminium matrix. The maximum hardness value observed based on Vickers micro hardness was 749.8 MPa for 30 Wt. % of crystalline silica particulate addition while pure aluminium shows hardness value 386.4 MPa.

#### 4.8 Potentiodynamic polarization

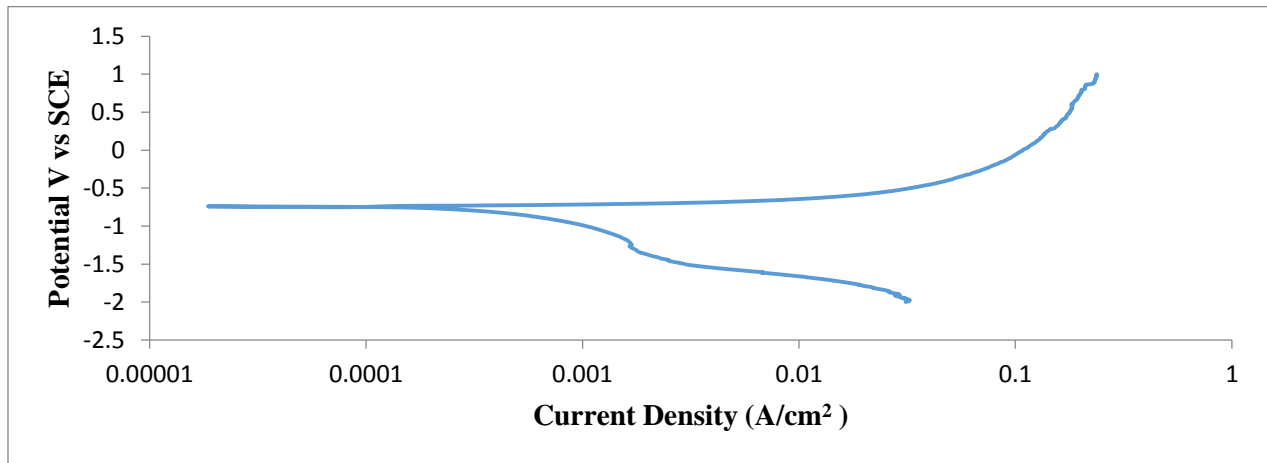


Fig. 11. Potentiodynamic polarization of pure aluminium in sea water solution

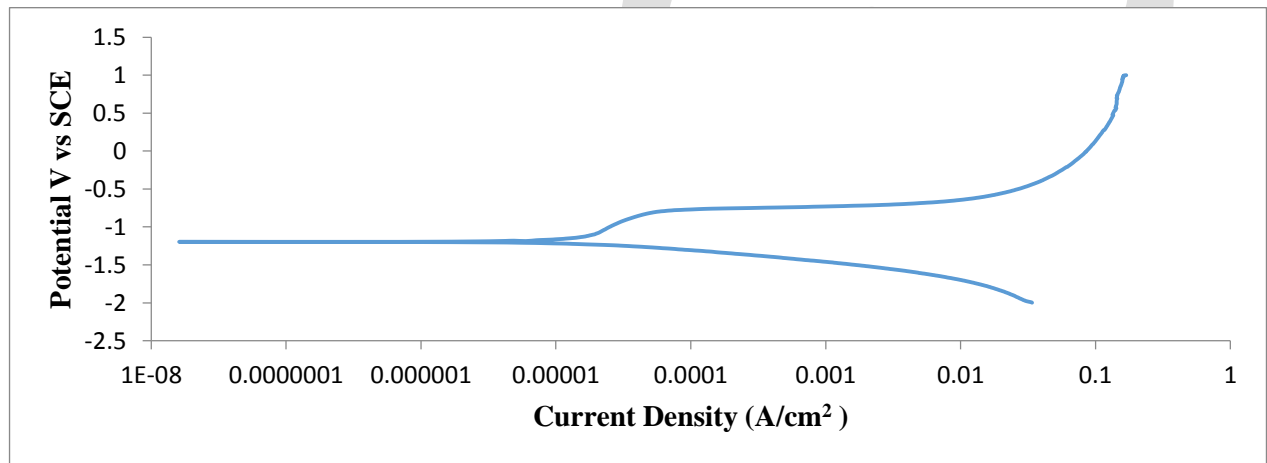


Fig. 12, Potentiodynamic polarization after adding 20 Wt. % silica particulates on aluminium matrix in sea water solution

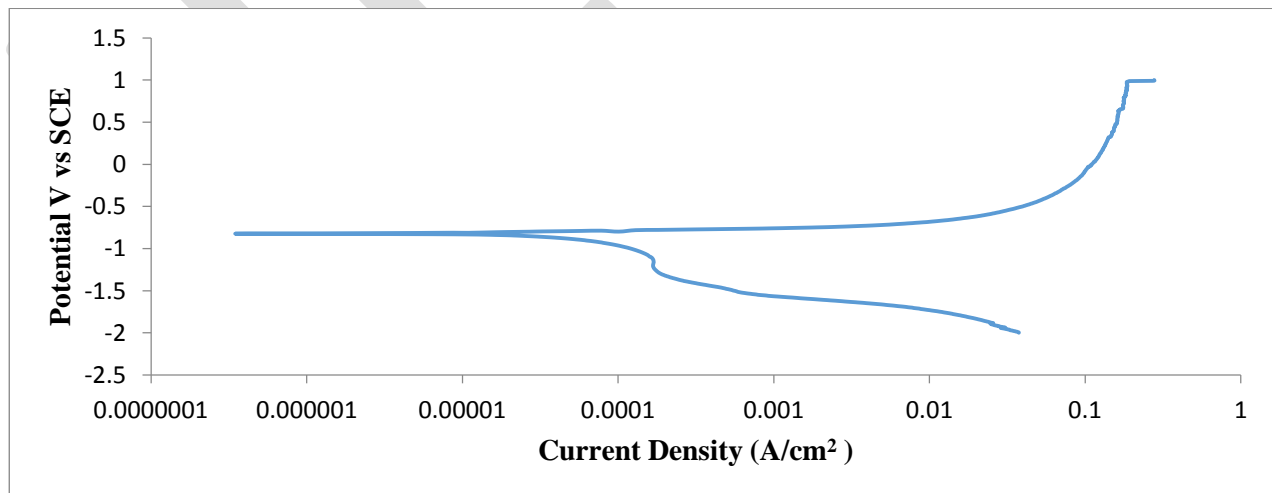


Figure 13, Potentiodynamic polarization after adding 30 Wt. % silica particulates on aluminium matrix in sea water solution

Figure 11 represents the potentiodynamic polarization for pure aluminium in 3.5% NaCl solution. After addition of 20 Wt. % and 30 Wt. % crystalline silica particulates on aluminium matrix, potentiodynamic polarization changes as shown in figure 12 and figure



13 respectively, in seawater solution. The corrosion current density  $i_{\text{corr}}$  for pure aluminium is  $0.0017 \text{ A/cm}^2$  while after addition of 20 Wt. % and 30 Wt. % crystalline silica particulates,  $i_{\text{corr}}$  changes from  $0.0005 \text{ A/cm}^2$  to  $0.00045 \text{ A/cm}^2$ . Clearly corrosion current density  $i_{\text{corr}}$ , hence corrosion rate, decreases with increasing weight percent addition of silica particulates on aluminium matrix. This result shows the role of crystalline silica particulates on aluminium matrix to increase corrosion resistance with covering the anodic sites and enhancing the passivity of surface and finally reduces the dissolution of aluminium; hence increase the life span of the material.

## CONCLUSION

The significant conclusions of the studies on crystalline silica- aluminium composites are as follows:

- Crystalline silica-aluminium composites were developed successfully using powder metallurgy technique.
- The experiments showed that an extruded mixture of crystalline silica and commercial powder aluminium heated at  $600^{\circ}\text{C}$  for one hour using hot press promote no reaction between matrix and reinforcement.
- Morphology obtained from optical microscope and SEM was found to the uniform distribution of crystalline silica in aluminium matrix.
- The density of crystalline silica-aluminium composites were decreased slightly with the increased of silica content. Soft aluminium matrix reinforcement with crystalline silica particles, were able to improve mechanical property like Vickers micro-hardness significantly with the increment of crystalline silica content.
- Corrosion resistance, more accurately pitting corrosion of silica-aluminium composite was enhanced in sea water environment with the addition of crystalline silica particulates in aluminium matrix.

## REFERENCES:

- [1] Bharath; V Nagaral; M; Auradi; V., "Preparation of 6061Al-Al<sub>2</sub>O<sub>3</sub> metal matrix composite by stir casting and evaluation of mechanical properties", International Journal of Metallurgical & Materials Science and Engineering, Vol.2, Issue 3, ISSN(Print)- 2278-2516; ISSN(Online)- 2278-2524; pp. 22-31, 2012.
- [2] Kleme; S.A; Reponen; P.K.; Liimatainen; J.; Hellman; J; Hannula; S.P., "Abrasive wear properties of metal matrix composites produced by hot isostatic pressing", Proc. Estonian Acad. Sci. Eng., vol. 12, Issue no.4, ISSN- 1406-0175, pp 445-454, 2006.
- [3] Toptan, F.; A. Karaaslan; A.; Cigdem; M; Kerti, "Processing and microstructural characterization of AA 1070 and AA 6063 matrix B4Cp reinforced composites", Materials and Design 31, ISSN- 0264-1275, pp.87-91, 2009.
- [4] Chawla, N. and Chawla, K. K., "Metal Matrix Composites in ground transportation," Springer-Verlag, New York, ISSN (Print)- 895-4852, ISSN (Online)- 1936-4709, pp- 401, 2006.
- [5] Sannino, A. P. and Rack, H. J., "Dry Sliding Wear of Discontinuously Reinforced Aluminium Composites: Review and Discussion," Wear, 189, 1-2, 1995, 1-19, 1995.
- [6] Sinclair, I. and Gregson, P. J., "Structural Performance of Discontinuous Metal Matrix Composites," Material Science and Technology, Print ISSN- 0267-0836, Online ISSN- 1743-2847, 13, 9, 709-726, 1997.
- [7] S.V Prasad and R.Asthana, 'Aluminium metal matrix composites for automotive applications; Tribological Considerations', Tribology Letters, ISSN: 1023-8883 (Print) 1573-2711 (Online), Vol. 17, No.3 October 2004
- [8] Z.RazaviHesabi, A.Simchi and S.M. Syed Raihani, 'Structural evolution during mechanical milling of nanometric and micrometric Al<sub>2</sub>O<sub>3</sub> reinforced Al matrix composites', Materials Science and Engineering, ISSN: 0921-5093, A428, 2006
- [9] X.C.Tong and A.K.Ghosh, "Fabrication of in situ TiC reinforced Aluminum matrix composites", Journal of Materials Science, ISSN: 0022-2461 (Print) 1573-4803 (Online), 36, 4059-4069, 2001
- [10] M.Magesh,L. John Baruch, D. George Oliver, "Microstructure and Hardness of Aluminium Alloy- Fused Silica Particulate Composite", International Journal of Innovative Research in Advanced Engineering (IJRAE), ISSN: 2349-2163, Volume 1 Issue 5, 2014
- [11] A.M.S. Hamouda; S. Sulaiman ; T.R Vijayaram ; M. Sayuti; M.H.M. Ahmad., "Processing and characterization of particulate reinforced aluminium silicon matrix composite", Journal of Achievements in Materials and Manufacturing Engineering, ISSN: 2249-6645, Volume 25, Issue 2, 2007.
- [12] A. M. Usman, A. Raji, N. H. Waziri and M. A. Hassan, "Production and Characterization of Aluminium Alloy - Bagasse Ash Composites", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 11,

Issue 4 Ver. III (Jul- Aug. 2014), PP 38-44, 2014

- [13] M. M. Dave, K. D. Kothari, "Composite Material-Aluminium Silicon Alloy: A Review", Volume- 2, Issue : 3, ISSN- 2250-1991, 2013
- [14] X.C.Tong and A.K.Ghosh, 'Fabrication of in situ TiC reinforced Aluminum matrix composites', Journal of Materials Science, ISSN: 0022-2461 (Print) 1573-4803 (Online), 36, 4059-4069, 2001
- [15] S.ghosh et al., 'Preparation of Ti-Aluminide reinforced in situ Aluminum matrix composites by Reactive Hot Pressing', Journal of Alloys and Compounds doi: 10.1016/j.jallcom.2006.07.017, ISSN: 0925-8388, 2006
- [16] M.J.Flonas-Zamora et al., 'Aluminum-Graphite composite produced by mechanical milling and hot extrusion', Journal of Alloys and Compounds doi: 10.1016/j.allcom.2006.08.145, ISSN: 0925-8388, 2006
- [17] H.Huo et al., 'In situ synthesis of Al<sub>2</sub>O<sub>3</sub> particulate reinforced Al matrix composite by low temperature sintering', Journal of Materials Science, ISSN: 0022-2461 (Print) 1573-4803 (Online), 41, 3249-3253, 2006
- [18] Zhongliang Shi, 'The oxidation Of SiC Particles and its interfacial characteristics in Al-Matrix composite', Journal Of Materials Science, ISSN: 0022-2461 (Print) 1573-4803 (Online), 36, 2441 – 2449, 2001