

## Mechanical Behaviour of As-Cast and Heat-Treated: AA2024 Alloy-Silicon Carbide-Al<sub>2</sub>O<sub>3</sub> Hybrid Composites

### Abstract

This paper reports on the mechanical properties of as-cast and heat-treated AA2024 alloy hybrid composites reinforced with SiC/Al<sub>2</sub>O<sub>3</sub> from 1 to 5 wt %. The hybrid composites were fabricated using the Compocasting method, in which short SiC/Al<sub>2</sub>O<sub>3</sub> were introduced into the vortex created in the molten alloy through an impeller rotated at 500 rpm. The molten mass was thoroughly stirred and poured into permanent molds and squeezed under pressure. The specimens were heat treated at 575°C for 1, 2, 3, and 4 h. The tests on the as-cast hybrid composites revealed that as the glass content in the hybrid composites was increased, the ultimate tensile strength (UTS), compressive strength, and hardness of the composite increased, while the ductility and impact strength were decreased. Heat treatment was found to improve significantly the ductility, compressive strength, and impact strength, while the hardness and UTS were reduced. This paper discusses the behavior of these hybrid composites.

**Keywords:** Hybrid composites, SiC/Al<sub>2</sub>O<sub>3</sub>  
Mechanical properties, Al alloys

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## INTRODUCTION

Over the past four decades, there have been pioneering efforts to develop metal-matrix hybrid composites (HCs) as new engineering materials having improved properties and lightweight in comparison with traditional materials [1]. The outstanding benefit of metal matrix hybrid composites (HCs) is that they combine metallic properties with ceramic properties, thus yielding attractive physical and mechanical properties [2]. The matrix materials used in HCs are usually popular alloys selected mainly on the basis of their already established superior properties [3]. For good bonding and strength in hybrid composites, metal alloys are used as the matrix elements instead of pure metals [4]. Ceramic reinforcements are generally used because of their combination of high strength and stiffness at both room and elevated temperatures [4]. During the last few years several studies of the mechanical behavior of discontinuously reinforced hybrid composites have been reported [5,6]. Hybrid composites reinforced with randomly oriented short fibers have become increasingly popular in recent years [7]. In the design of such hybrid composites, it is essential to understand the strengthening mechanism and the relationship between the strength of the composite and the properties of the components [8]. The short-fiber-reinforced HCs have shown improved modulus of

elasticity and tensile strength, whereas particle reinforcement improves the hardness and damping properties and also lowers the coefficient of thermal expansion [9]. Moreover, short-fiber-reinforced hybrid composites are used because they tend to be less expensive and more amenable to mass production techniques than continuous fiber hybrid composites; they represent an economic compromise. The performance re

Lationships and the ease of fabrication are influenced by the interface between the matrix and the reinforcing phase [10]. Various studies on reinforcement interfaces have been made to determine the factors that dictate bonding and interface behavior [11,12].

The aluminum (AA) family of alloys, which are often the first choice to replace cast iron, brass, or aluminum alloys [13], are popular alloys for matrix materials. The AA2024 alloy, which was developed by the Canadian Organization of Noranda Mines Limited, is a high-strength alloy whose properties can be equivalent to those of aluminum alloys [14]. The AA2024 alloys have been used in bearings, bushings, and other wear-resistant applications as a replacement for bronze bearings due to their lower cost and equivalent or superior performance [15]. The present investigation evaluated the mechanical properties of the AA2024/SiC/Al<sub>2</sub>O<sub>3</sub> hybrid composites in both the as-cast and heat-treated conditions.

## **EXPERIMENTAL PROCEDURE**

### ***Preparation of the Hybrid composites***

AA2024 alloy (Al-Balance, 0.01 to 0.02 wt% Mg, 2.0 to 2.5 wt% Cu, bal Zn) was used as the base matrix alloy. E-glass was used as the reinforcement. The diameter of the fibers was 4 to 5  $\mu\text{m}$  and the length was 4 to 6 mm. The AA2024/glass-fiber hybrid composites were fabricated using the Compocasting technique, which is similar to the one used by Hosking et al. This is the most economical method of fabricating hybrid composites with discontinuous fibers. The matrix alloy (AA2024) was first superheated above its melting temperature, and stirring was initiated to homogenize the temperature. The temperature was then lowered gradually until the alloy reached a semisolid state. At this temperature (440°C) the SiC/Al<sub>2</sub>O<sub>3</sub> were introduced into the slurry. During the addition of SiC/Al<sub>2</sub>O<sub>3</sub> the temperature was raised gradually and stirring was continued until the interface between the fibers and the matrix promoted wetting. The melt was then super-heated above its liquidus temperature of 500°C and was finally poured into the lower die-half of the press. The top die was brought down and high pressure was applied to solidify the composite.

The specimens were heat treated at 575°C for 1, 2, 3, and 4 h and were subsequently air cooled. The durations and temperature were selected based on the reports of other researchers [14].

### ***Testing of Specimens***

The tension tests were performed at room temperature using a universal testing machine the tensile test was conducted according to ASTM E 8-82. The specimens were machined from the cast hybrid composites with the gage length of specimens parallel to the longitudinal axis of the castings. As many as eight tensile specimens were tested for each case and the average values of the tensile strength.

## **MECHANICAL BEHAVIOUR TEST (HEAT TREATMENT WEIGHT LOSS METHOD)**

### **% of weight loss of cast and heat treated specimens in HCl solution.**

#### **Effect of corrosion test duration:**

The results in tables 1 to 4 shows that, for each hybrid composites as well as for the unreinforced zinc alloy, whether heat treatment was performed or not, the corrosion rate seems to decrease with duration of the corrosion test. The phenomenon of gradually decreasing corrosion rate is probably due to the presence of aluminium in the zinc alloy. Pure zinc, which is commonly used as a sacrificial anode in galvanic corrosion systems, corrodes readily in HCl solution. However, the relatively large amount of aluminium present in the zinc alloy matrix probably confers a certain amount of corrosion resistance since aluminium is known to form a protective layer of aluminium oxide on its surface,

which 'is quite stable in neutral and many acid solutions but is attacked by alkalis. The SiC &  $\text{Al}_2\text{O}_3$  are inert and they are of no consequence in this case.

**Table 1: % Weight loss for as – cast (non-heat treated) Specimens**

| SiC & $\text{Al}_2\text{O}_3$<br>Content (%) | Time of Exposure |       |       |       |       |       |
|--|------------------|-------|-------|-------|-------|-------|
|  | 12hr             | 24hr  | 36hr  | 48hr  | 60hr  | 72hr  |
| 0+0  | 2.543            | 2.332 | 2.041 | 1.694 | 1.332 | 1.113 |
| 2+1  | 2.249            | 2.261 | 1.941 | 1.510 | 1.107 | 1.000 |
| 2+3  | 1.851            | 1.511 | 1.319 | 1.118 | 0.844 | 0.586 |
| 2+5  | 1.548            | 1.324 | 1.104 | 0.894 | 0.651 | 0.443 |

**Table 2: % Weight loss for Specimens heat-treated for 2 hours**

| SiC & $\text{Al}_2\text{O}_3$<br>Content (%) | Time of Exposure |       |       |       |       |       |
|--|------------------|-------|-------|-------|-------|-------|
|  | 12hr             | 24hr  | 36hr  | 48hr  | 60hr  | 72hr  |
| 0+0  | 1.781            | 1.432 | 1.236 | 1.008 | 0.886 | 0.646 |
| 2+1  | 1.549            | 1.392 | 1.009 | 0.913 | 0.773 | 0.411 |
| 2+3  | 1.246            | 1.119 | 0.943 | 0.743 | 0.511 | 0.309 |
| 2+5  | 1.134            | 0.911 | 0.794 | 0.643 | 0.544 | 0.494 |

**Table 3: % Weight loss for Specimens heat-treated for 3 hours**

| SiC Content<br>(%) | Time of Exposure |       |       |       |       |       |
|--------------------|------------------|-------|-------|-------|-------|-------|
|                    | 12hr             | 24hr  | 36hr  | 48hr  | 60hr  | 72hr  |
| 0+0                | 1.680            | 1.402 | 1.200 | 1.000 | 0.713 | 0.510 |
| 2+1                | 1.493            | 1.300 | 0.948 | 0.876 | 0.683 | 0.329 |
| 2+3                | 1.136            | 1.009 | 0.810 | 0.703 | 0.432 | 0.213 |
| 2+5                | 0.903            | 0.893 | 0.743 | 0.613 | 0.524 | 0.418 |

**Table 4: % Weight loss for Specimens heat-treated for 4 hours**

| SiC Content<br>(%) | Time of Exposure |       |       |       |       |       |
|--------------------|------------------|-------|-------|-------|-------|-------|
|                    | 12hr             | 24hr  | 36hr  | 48hr  | 60hr  | 72hr  |
| 0+0                | 1.413            | 1.246 | 1.134 | 1.000 | 0.919 | 0.846 |
| 2+1                | 1.296            | 1.000 | 0.894 | 0.809 | 0.734 | 0.632 |
| 2+3                | 1.100            | 0.836 | 0.764 | 0.711 | 0.600 | 0.541 |
| 2+5                | 0.891            | 0.771 | 0.698 | 0.610 | 0.504 | 0.409 |

#### **Effect of heat treatment**

The results in Fig 1 to 4 shows that heat treatment for 0, 2, 3, and 4 hours significantly improves the corrosion resistance of the hybrid composites irrespective of the SiC &  $\text{Al}_2\text{O}_3$  particulate contents, which may be due to the following reasons

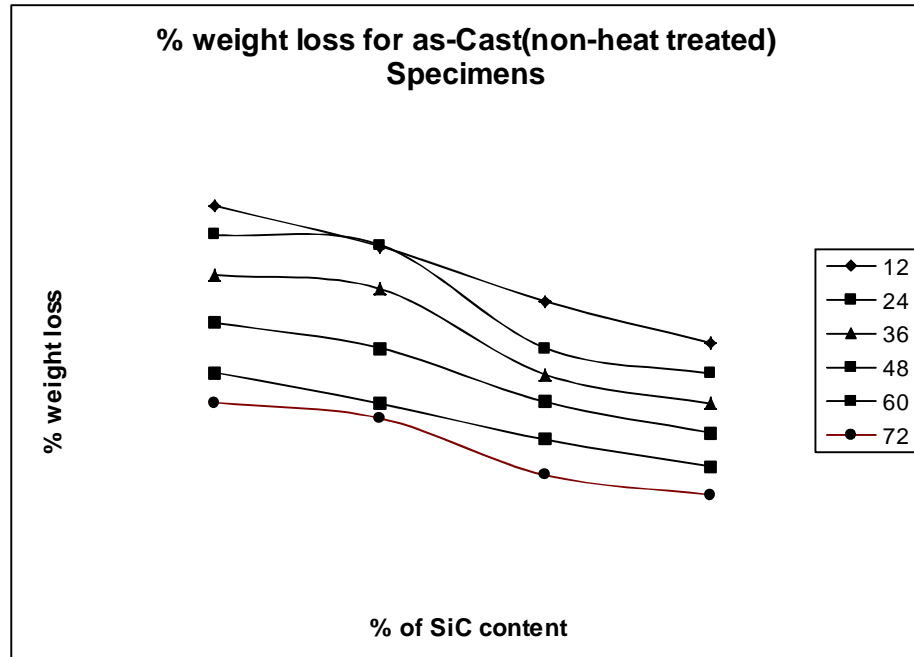


Figure 1: % Weight loss for as – cast (non-heat treated) Specimens

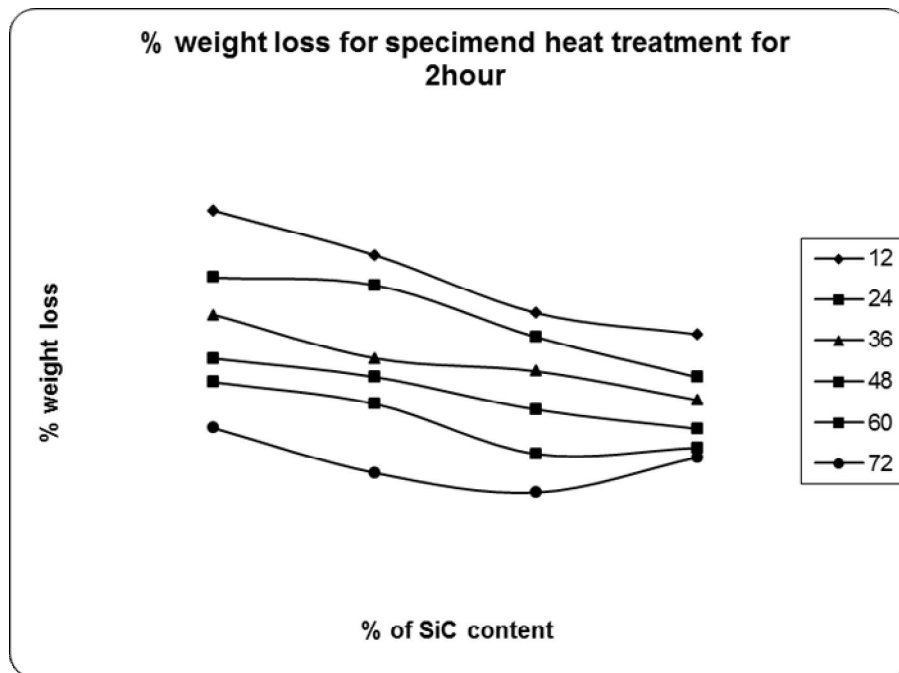


Figure 2: % Weight loss for Specimens heat-treated for 2 hours

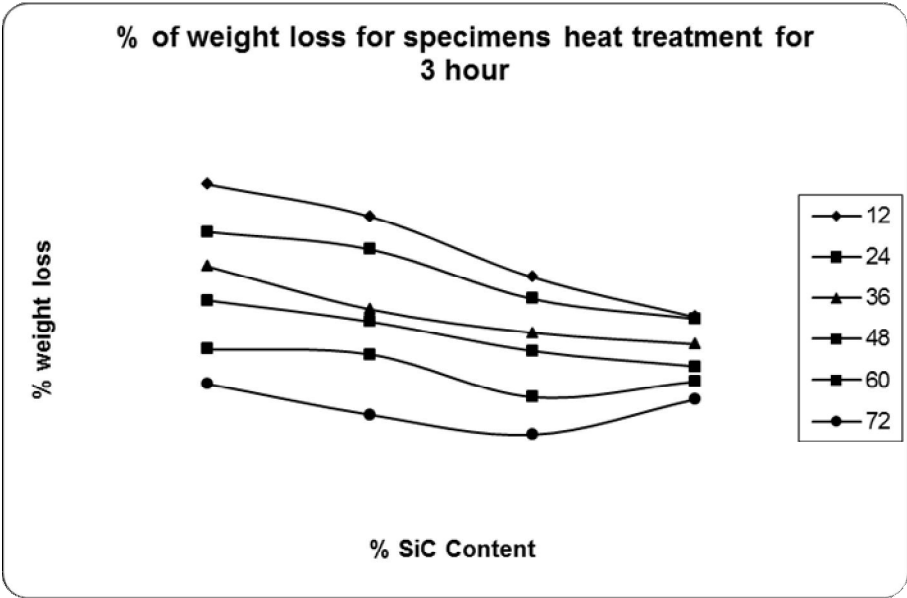


Figure 3: % Weight loss for Specimens heat-treated for 3 hours

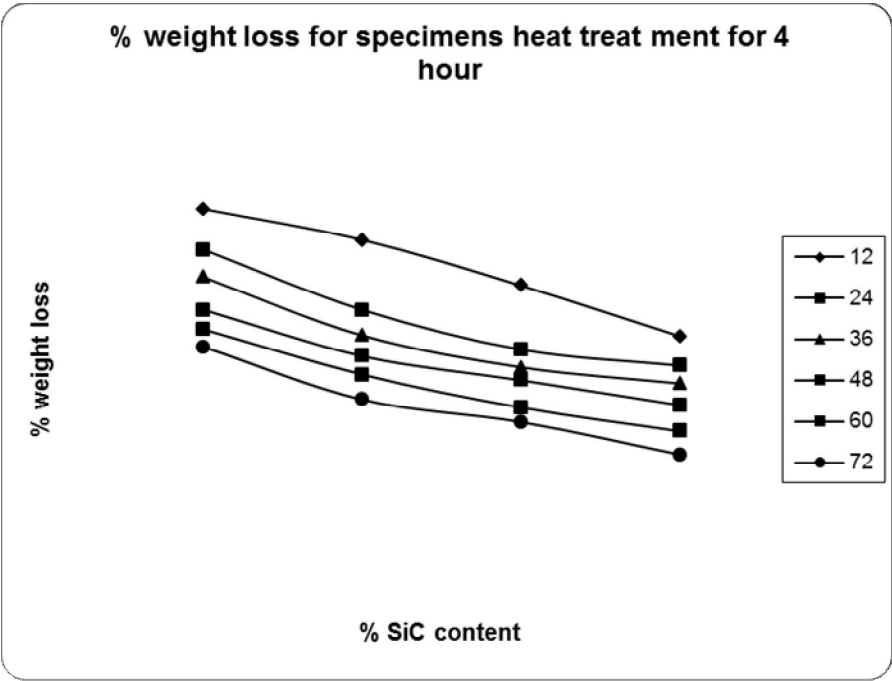


Figure 4: % Weight loss for Specimens heat-treated for 4 hours

- 1) Possibility of formation of a protective layer of aluminum oxide ( $\text{Al}_2\text{O}_3$ ) on the specimen due to heat treatment, which acts as a protective layer against corrosion.
- 2) A variation in the density of HCs, which can be attributed to the annihilation factor of lattice defect, by heat treatment (above recrystallisation temperature). It results in improved homogeneous nature of hybrid composites, which increases the corrosion resistance of HCs.
- 3) By heat treatment there is a possibility of plastic yielding, which helps to relieve residual stresses in the composite specimens, reducing the mismatch strain which may be one of the reasons for the increase in the corrosion resistance of both the alloy and HCs.

Due to these reasons, % weight loss decreased with increasing heat treatment time. It can be said that heat treatment for a period of 2 hours causes the % weight loss to drop. On further heat treatment for 3 hours and 4 hours, specimens were seen little more corrosion resistant, than the 2-hour heat treatment specimens. One possibility is that heat treatment at  $395^\circ\text{C}$  has introduced an overall enhancement in all the specimens, unreinforced as well as reinforced, no matter what ever the SiC content is.

## CONCLUSION

### Effect of SiC Content

From tables 1 to 4 it can be clearly seen that for each heat treatment condition, the % weight loss due to corrosion decreases monotonically with SiC content. In other words, the more SiC is added, the greater the corrosion resistance of the composite. Actually the SiC are inert and are not expected to affect the corrosion mechanism of the composite. However, when the SiC content is increased, there is less matrix material to corrode and this result in an expected reduction in the corrosion weight loss observed. Still, the corrosion weight loss observed seems to be considerably more than proportionate with the percentage of SiC added. Quantitatively, adding 6% of SiC to the alloy matrix reduces corrosion weight loss by about 50%. This shows that, although the SiC are inert, they nevertheless protect the matrix somewhat from corrosion by some mechanism which the authors are unable to explain thoroughly at this stage.

### Microstructure of Etched AA2024 and AA2024/SiC & $\text{Al}_2\text{O}_3$

In Figs. 5-8 the Microstructures play an important role in the overall performance of an alloy as well as a composite. The physical properties depend on the microstructure, particle size, shape and distribution in the matrix alloy. Figs. 5-6 shows typical microstructures of the AA2024 and HCs containing 6-wt. % SiC. The observations show that the size of the SiC &  $\text{Al}_2\text{O}_3$  particles is within 50-60  $\mu\text{m}$ . The grain size of matrix alloy is somewhat larger than that of the hybrid composites. There were large clusters of SiC within some areas of the matrix while other areas were entirely SiC &  $\text{Al}_2\text{O}_3$  depleted.

At higher magnifications, the analysis of the structure (Fig. 7) reveal that the relatively colder particle chills the metal and unitized nucleation. The dendrites grow away from the particle due to the restriction caused by the particle to solute enrichment. Thus the grains grow outwards from the particle and the last remaining eutectic liquid solidifies around the particles. However, no gap is observed between the particle and the matrix, and the particles are seen well bonded with the matrix.

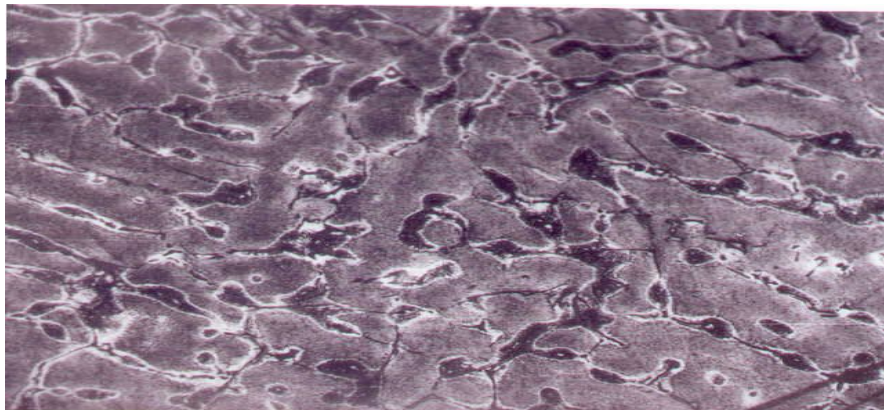


Figure 5: Microstructure of the AA2024 as-cast alloy (100 $\mu\text{m}$ )

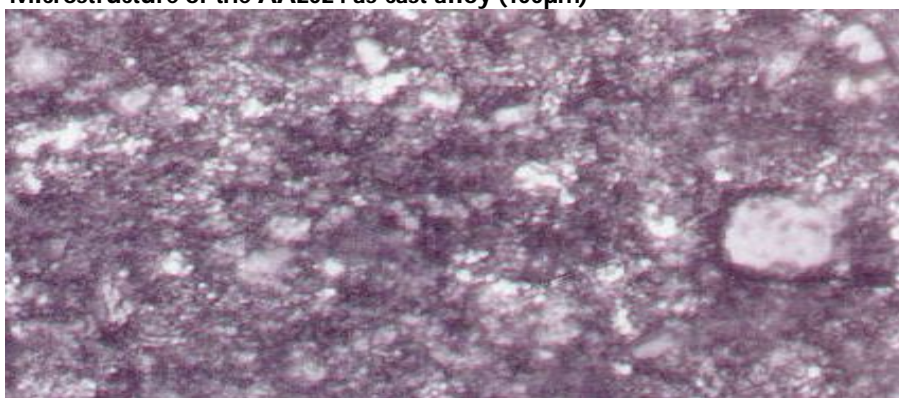


Figure 6: Microstructure of AA2024/ 2+1% SiC &  $\text{Al}_2\text{O}_3$  hybrid composites (100 $\mu\text{m}$ )

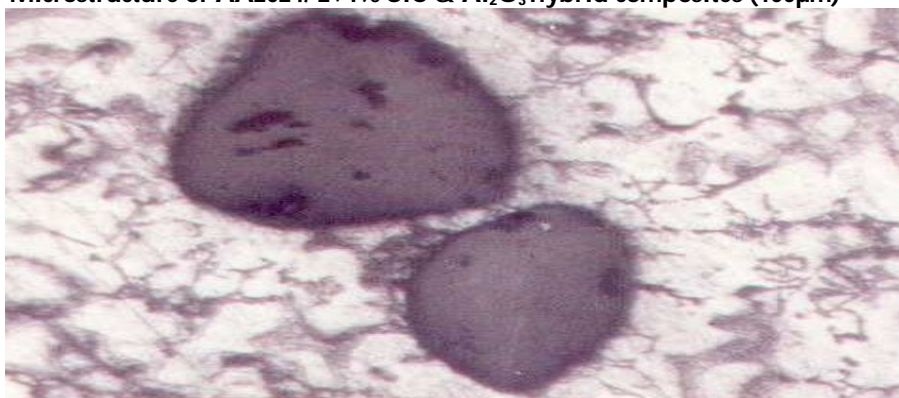


Figure 7: Microstructure of AA2024/ 2+5% SiC &  $\text{Al}_2\text{O}_3$  hybrid composites (Higher magnification)

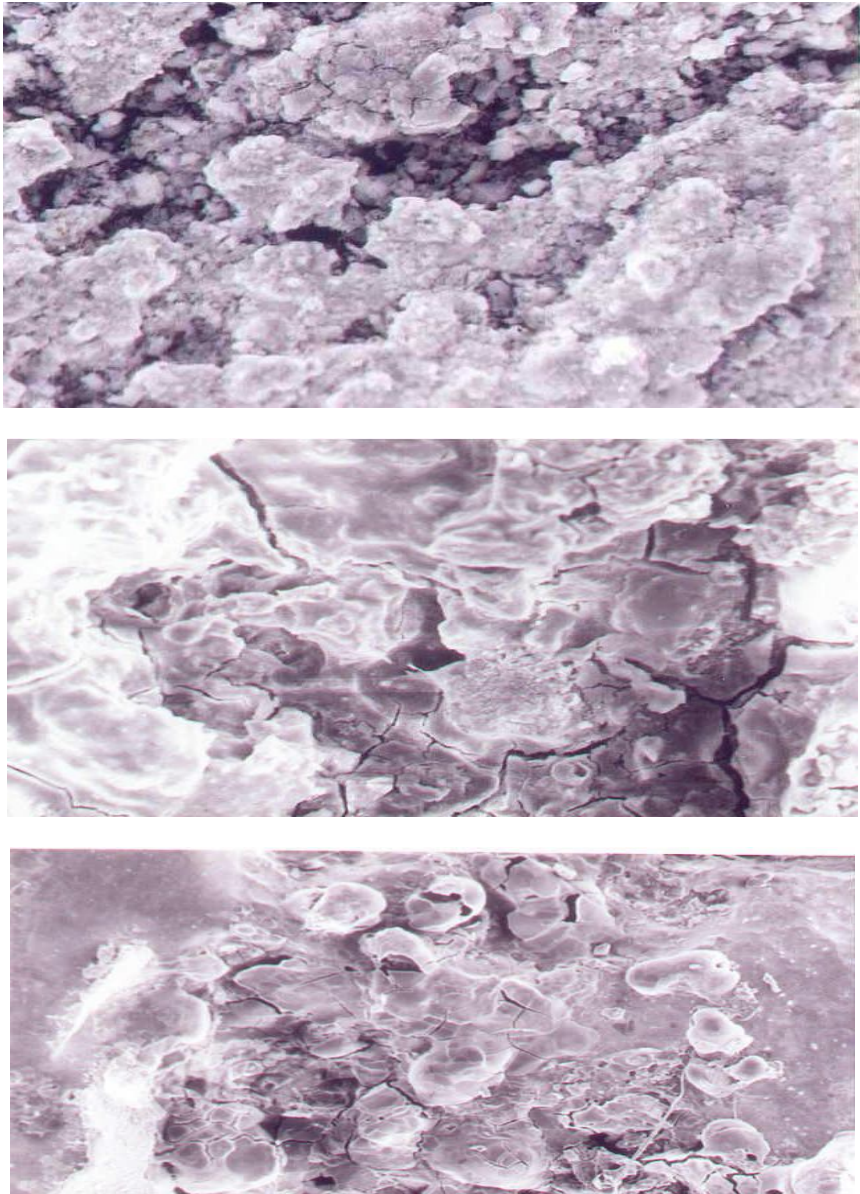


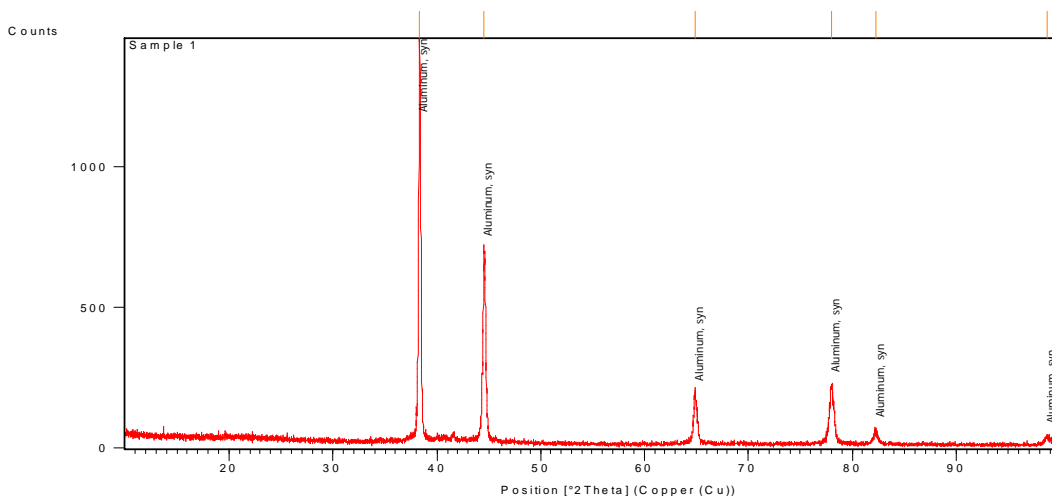
Figure 8: Corroded surface of AA2024/ SiC & Al<sub>2</sub>O<sub>3</sub> after weight loss corrosion test(100µm)

**XRD-Studies:**

**Measurement Conditions:** (Bookmark 1)

|                            |  |
|----------------------------|--|
| Dataset Name               | Sample 1(AL 1100)  |
| File name                  | C:\X'Pert Data\AIT\Dr. Bheema\Sample 1.xrdml                 |
| Comment                    | Configuration=MPSS (vertical system), Owner=User-1, Creation |
| date=7/14/2006 11:40:02 AM |  |
| Raw Data Origin            | XRD measurement (*.XRDML)                                    |
| Scan Axis                  | Gonio  |
| Start Position [°2Th.]     | 10.0042  |
| End Position [°2Th.]       | 99.9882  |
| Step Size [°2Th.]          | 0.0080   |

Scan Step Time [s] 10.7950  
 Scan Type Continuous  
 PSD Mode Scanning  
 PSD Length [°2Th.] 2.12  
 Offset [°2Th.] 0.0000  
 Divergence Slit Type Fixed  
 Divergence Slit Size [°] 0.9570  
 Specimen Length [mm] 10.00  
 Measurement Temperature [°C] 25.00  
 Anode Material Cu  
 K-Alpha1 [Å] 1.54060  
 K-Alpha2 [Å] 1.54443  
 K-Beta [Å] 1.39225  
 K-A2 / K-A1 Ratio 0.50000  
 Generator Settings 30 mA, 40 kV  
 Diffractometer Type 0000000011014412  
 Diffractometer Number 0  
 Goniometer Radius [mm] 240.00  
 Dist. Focus-Diverg. Slit [mm] 91.00  
 Incident Beam Monochromator No  
 Spinning No



**Figure 9: XRD of AA2024 alloy**

| Pos. [°2Th.] | Height [cts] | FWHM [°2Th.] | d-spacing [Å] | Rel. Int. [%] |
|--------------|--------------|--------------|---------------|---------------|
| 38.3321      | 1416.41      | 0.2204       | 2.34822       | 100.00        |
| 44.5368      | 675.81       | 0.2834       | 2.03443       | 47.71         |
| 64.9194      | 174.88       | 0.3149       | 1.43642       | 12.35         |
| 78.0022      | 204.22       | 0.4408       | 1.22500       | 14.42         |
| 82.2327      | 44.16        | 0.3779       | 1.17237       | 3.12          |
| 98.7606      | 27.25        | 0.7680       | 1.01482       | 1.92          |

**Pattern List:**

| Ref. Code   | Score | Compound Name | Displacement [°2Th.] | Scale Factor | Chemical Formula |
|-------------|-------|---------------|----------------------|--------------|------------------|
| 00-004-0787 | 86    | Aluminum, syn | 0.000                | 0.357        | Al               |

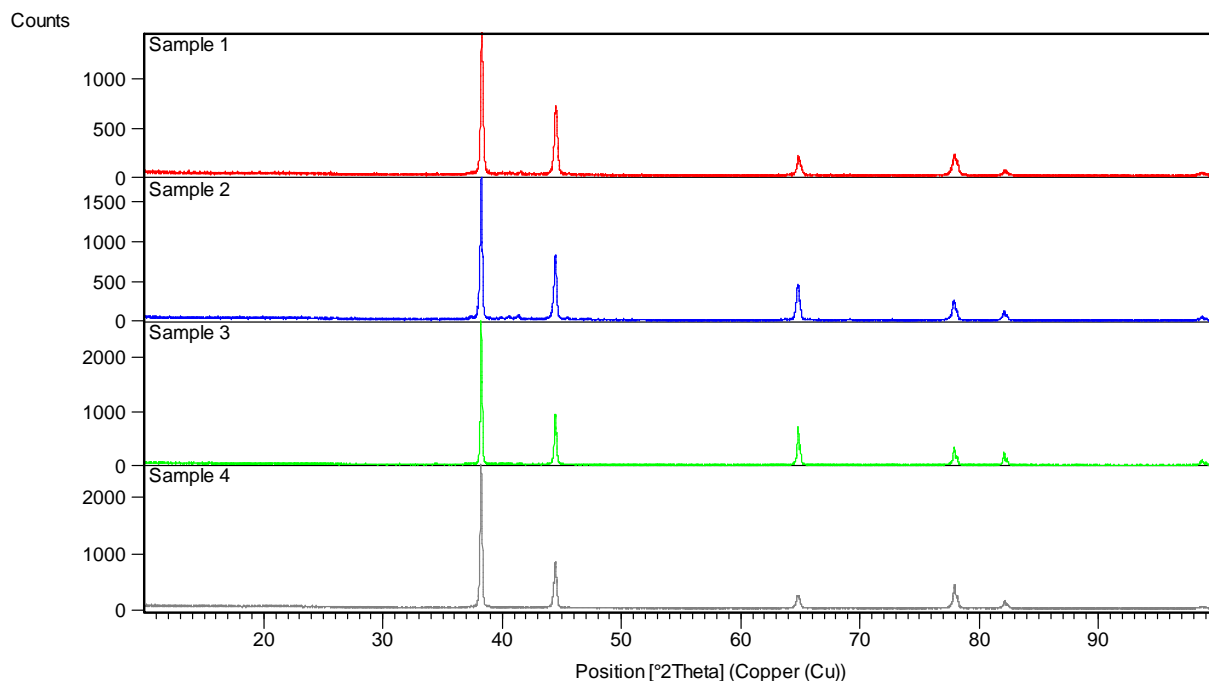


Figure 10: XRD of all samples

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