

# Experimental Investigation of Al-6061 Metal Matrix Composite Reinforced with Selenium

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**Abstract.** The creation of innovative materials with essential properties is required due to the industry's rapid advancements. The most desirable properties of metals used in the aerospace industry, automotive industry, and marine industry are hardness, compression, shear, etc. Aluminium metal matrix composites (AMMCs) are effective and meet industrial standards. This study focuses on the influence of reinforcement particles (Selenium) on Al-6061 by using the stir-casting fabrication method and the composites are prepared. Mechanical characteristics are studied by varying Selenium weight percentages such as 0.5%, 1%, and 1.5%. Based on the Mechanical tests it is noticed that there is an improvement in Mechanical strength such as tensile strength, flexural strength, and compression strength by 32%, 29.5%, and 25% at 1 Wt% of Selenium. By implying the Powder XRD test on the prepared sample which is a significant parameter drawn from mechanical tests, based on the Standard XRD data it is noticed that a Hexagonal Crystal Structure is formed.

Keywords: Al-6061, Selenium, Stir casting, Mechanical Tests, XRD test.

## 1 Introduction

Metal matrix composites (MMCs) emerged as a strong material class with a distinctive set of qualities that appeal to a variety of applications. These composites consist of a metal matrix reinforced with one or more secondary materials, such as ceramics, fibres, or particles. One of the primary motivations for investigating MMCs[1] is their improved mechanical properties. The addition of reinforcements within the metal matrix enhances its strength, stiffness, and wear resistance. The selection of reinforcement material depends on the desired properties such as (Hardness, Strength, etc), with popular options including ceramic particles, Fibers (such as carbon, silicon carbide, or alumina), and whiskers.

Aluminium alloy 6061, also known as Al-6061, is a widely used and highly versatile material in various industries. It is an Aluminium alloy that comes from the 6xxx series, [2] which is

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recognized for its exceptional strength-to-weight ratio and good formability. Al-6061 offers a unique combination of mechanical properties, suitable for applications [3] in aerospace, automotive, construction, etc. The composition of Al-6061 primarily consists of aluminium, magnesium, and silicon with negligible amounts of other elements. This alloy exhibits exceptional strength and stiffness, enabling it to withstand high loads and stresses while maintaining structural integrity. Its strength-to-weight ratio makes it particularly advantageous [4] for applications where weight reduction is crucial without compromising performance. The presence of magnesium and silicon enhances [5] its ability to withstand corrosive environments, including atmospheric conditions and certain chemicals. This corrosion resistance [6] contributes to the longevity and durability of components made from Al-6061, ensuring their reliability in a wide range of operating conditions.

The current work is an inquiry into the influence of Selenium particles in Al- 6061. The Specific reason behind choosing Selenium as a reinforcement is some similar minerals like Magnesium, etc are to be found which may affect strength in an incremental way. The stir-casting process is used to fabricate three samples by varying weight percentages of Selenium (0.5, 1 & 1.5). These samples are tested to study mechanical characteristics such as tensile strength, flexural test, compression strength, and hardness. Later the Powder XRD test is performed on the Al-Se composite to identify its crystal structure.

## 2 Materials & Fabrication Method

### 2.1 Materials

The Al-6061 Alloy bars are acquired from the Sachin Steel Center in Mumbai, India. Sigma Aldrich in Bangalore, Karnataka, India provided the selenium particles. Table 1. [7] lists the chemical composition of the matrix Aluminium alloy 6061.

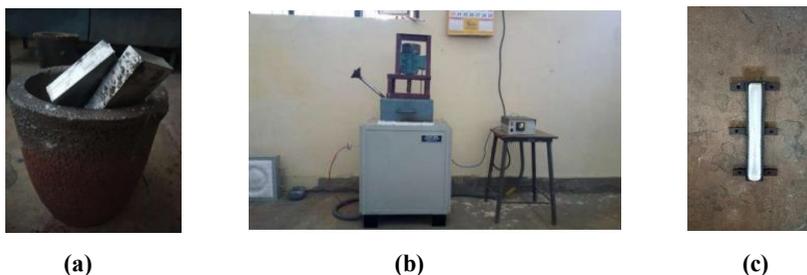
**Table 1.** Composition of matrix material

Constituent	Al	Mg	Si	Fe	Cu	Zn	Mn	Cr	Other
Wt. %	96.5	0.956	0.562	0.532	0.236	0.202	0.102	0.046	0.864

### 2.2 Fabrication Method

In this work, Al-6061 material is considered as a matrix, and the micro-size Selenium particles are considered as reinforcement. The samples are fabricated using a stir-casting process. Initially, the Al-6061 is heated up to 850-900°C (Fig. 1.) for complete melting. After that, the Selenium particles are added and stirred to get a uniform mixture. A metallic die made up of cast iron gets filled with the molten melt and it is kept in an open environment to cool down for easy removal from the mold on its own. The entire process is repeated to prepare new samples by varying weight percentages. The samples are:

- S1: 99.5 wt.% of Al6061 + 0.5 wt.% of Selenium
- S2: 99 wt.% of Al6061 + 1 wt.% of Selenium
- S3: 98.5 wt.% of Al6061 + 1.5 wt.% of Selenium



**Fig. 1.** (a)Al-6061 material in Graphite crucible (b)Experimental Setup (c)Al6061- Se composite Mold.

### 3 Results and Discussion

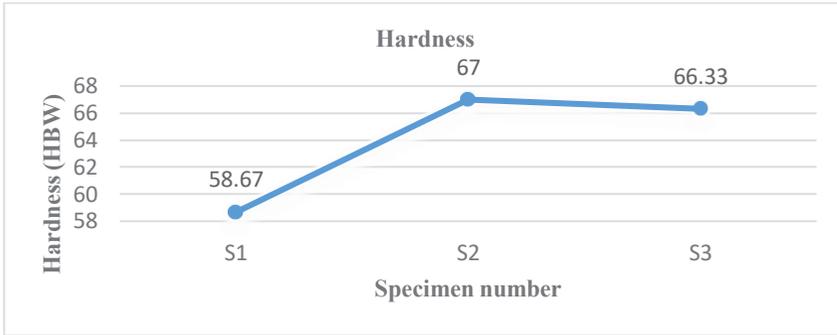
Mechanical tests have been carried out and detailed below to study the mechanical properties of fabricated Al-Se composite material.

#### 3.1 Hardness test

The specimens' hardness is determined by performing Brinell hardness test. A Brinell hardness test instrument that has an indenter radius of five millimeters is employed in this investigation to determine the hardness of composite materials. The samples are fabricated with ASTM E10 guidelines. Each specimen receives an average of three readings (Table 2). The Al 6061-Se composites outperformed the aluminium alloy according to the findings of the hardness test (Fig. 2). The reinforcement (Se) presence in aluminium matrix increases the hybrid composites' resistance to plastic deformation.

**Table 2.** Composites' hardness values in HBW

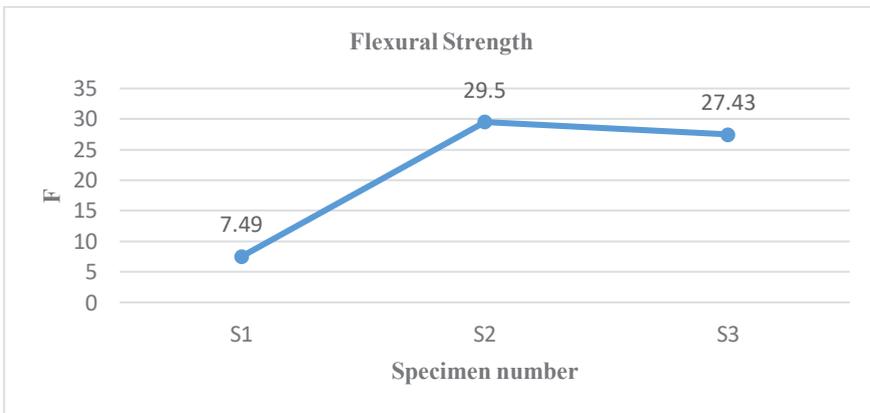
Specimen number	Composition	Reading 1	Reading 2	Reading 3	Average
S1	99.5 wt.% of Al6061 + 0.5 wt.% of Selenium	56	59	61	58.67
S2	99 wt.% of Al6061 + 1 wt.% of Selenium	67	65	69	67
S3	98.5 wt.% of Al6061 + 1.5 wt.% of Selenium	66	63	70	66.33



**Fig. 2.** Hardness Vs Specimen number

### 3.2 Flexural test

The rupture modulus test, generally known as the flexural strength test, it is a fundamental mechanical test used [8] to determine a material's capacity to endure bending or flexural loads. The material flexural strength is determined by subjecting a test specimen to a bending moment or a transverse load. This test gauges how composite materials respond to simple bending. The samples are fabricated in conformity with ASTM A370 guidelines. The samples were subjected to a flexural test using UTM. The samples' flexural strength is then compared with the base material's flexural strength, and it is observed that Sample 2 (S2) is found to have the highest breaking load and flexural strength of an increase of 29.5% than the other samples (Fig. 3). Also, in the Fig. 3 let  $(\sigma_s)/\sigma_o$  % be equal to F.



**Fig. 3.** Flexural Strength Vs Specimen number

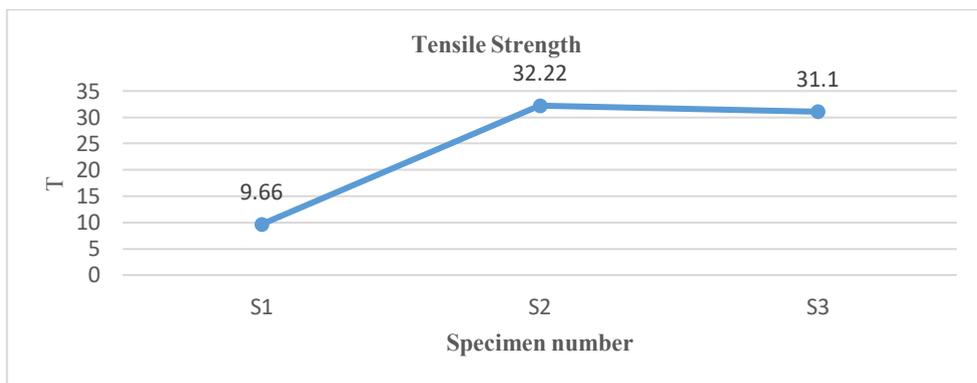
### 3.3 Tensile Strength

Materials often get selected for engineering applications [9] based on characteristics including modulus of elasticity, yield strength, and ultimate tensile strength. In this investigation, a test for tensile strength is done on a UTM (Universal Testing Machine), and the composite specimens S1, S2, and S3 are [10] manufactured in accordance with ASTM specifications. The material tensile behavior is varied by the varying levels of compositions. The Three specimens have different Young's modulus percentage elongation, percentage reduction, yield strength, and ultimate strength which are all measured by the universal testing machine (Fig.4 Samples before and after the tensile test). Fig. 5 shows the load-

deformation behavior of individual specimens and compositions, where it can also be observed that the tensile strength is increased by up to 32%. In fig 5 where  $(\sigma_s)/\sigma_o$  % is represented as T.



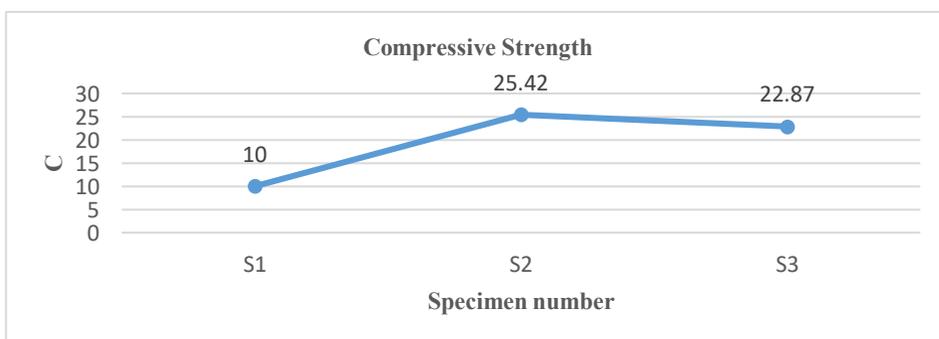
**Fig. 4.** Samples before and after the tensile test



**Fig. 5.** Tensile Strength Vs Specimen number

### 3.4 Compression Test

The compression test is a fundamental mechanical test used to evaluate the behavior and strength of materials under compressive forces. Compression testing involves [11] applying a compressive force or load on a test specimen in a controlled manner until it undergoes a significant deformation. To study the compressive strength of the material, a compressive test was performed on the prepared samples. The Compressive Strength of the materials varied by varying the levels of compositions as shown in Fig. 6. Among the three specimens, we can also observe that the compression strength was increased from 10% to 25% by an increase in the wt% of Selenium. In Fig 6, C denotes  $(\sigma_s)/\sigma_o$  %



**Fig. 6.** Compressive Strength Vs Specimen number

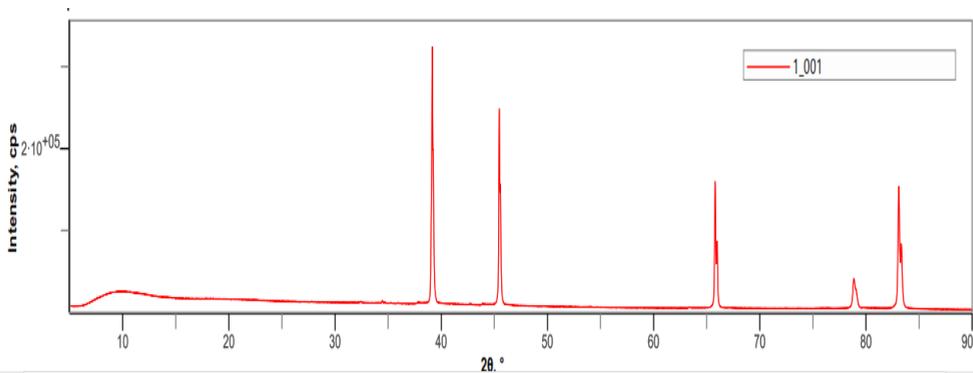
### 3.5 Powder XRD Test

The XRD technique is one of the key phase analysis methods used [12] in the MMC to assess the reaction between the alloy and ceramic components. The Powder XRD Test is performed to know more about the characteristics of crystalline materials. It is a non-destructive testing procedure that offers information on the material's structure. As the XRD test is performed on the Al-Se composite sample.

Now, the Al-Se composite sample is placed in a wire EDM machine to cut the sample into the required size of a 5mm, shape cube. Later, the specimen obtained after the wire EDM process is filed thoroughly on the surfaces of the cube. After filing the sample, it is placed in the Powder XRD machine, and a test is done on it. The output responses of the XRD test are obtained as shown in Table 3. Also, by using the raw data the graph is drawn and the peak points are found (Fig. 7).

**Table 3.** Experimental values of XRD experiment

S.No.	2θ°	Phase name	Chemical Formula	DB Card No	d-spacing, Å	Int I, cps°
1	39.047	Selenium: 1 0 1	Se	01-077-3596	2.30494	11983
2	39.139	Aluminium Titanium: 1 1 1	Al+x Til-x	00-42-1137	2.29970	30890
3	45.438	Selenium: 1 1 0, Aluminium Zinc: 0 1 2	Se, Al0.71, Zn0.29	01-077-3596, 00-019-0057	1.99448	31349
4	65.765	Aluminium Titanium: 2 0 2	Al+x Til-x	00-42-1137	1.418807	23272
5	78.817	Aluminium Zinc: 0 2 1	Al0.71, Zn0.29	00-019-0057	1.213350	10224
6	79.915	Selenium: 2 1 1	Se	01-077-3596	1.1995	309



**Fig. 7.** XRD graph 2θ° Vs Intensity, cps

As, from the above experimental data it can be observed that Selenium is identified at three 2θ° and those are 39.047°, 45.4383° and 79.915°. Also, it can be seen that traces of Aluminium Titanium and Aluminium Zinc are also identified in the XRD test.

The Crystalline size(D) depends on the Full-width Half Maximum (FWHM) (β) and 2 Theta (2θ) and the values of it are given below in Table 4. The values of dislocation density (δ) in nm<sup>-2</sup> and microstrain (ε) are given in Table 5 and by using the Bragg's equation the d-Spacing values are predicted. The experimental & predicted values of the d-Spacing are

given in Table 6. Also, From Table 6, it can be observed that the values of d-spacing values of both experimental and predicted ones match each other.

**Table 4.** Crystalline size (D)

2θ (degrees)	θ (degrees)	θ (radians)	FWHM (degrees)	FWHM (β) (radians)	D (nm)
39.047	19.5235	0.3407	0.100	0.001745	82.9908
45.4383	22.71915	0.3965	0.1029	0.001796	80.6346
79.915	39.9575	0.6974	0.87	0.01518	9.5406
<b>Crystalline Size</b>					173.166

**Table 5.** Dislocation density (δ) and Microstrain (ε)

D (nm)	δ(nm <sup>-2</sup> )	ε	ε *10 <sup>3</sup>
82.9908	1.45191*10 <sup>-4</sup>	0.073363	73.363
80.6346	1.53800*10 <sup>-4</sup>	0.064881	64.881
9.5406	0.01098622	0.311767	311.767

**Table 6.** Experimental and Predicted values of d-spacing

d-spacing Experimental	d-spacing Predicted
2.30494	2.30495
1.99448	1.99448
1.1995	1.19943

The Lattice parameters of Selenium from the experimental data are  $a = 3.98884 \text{ \AA}$ ,  $b = 3.98884 \text{ \AA}$ ,  $c = 3.09448 \text{ \AA}$ ,  $\alpha = 90^\circ$ ,  $\beta = 90^\circ$  and  $\gamma = 120^\circ$ . The Crystal System of Selenium is a Hexagonal Crystal where  $a = b \neq c$ , and  $\alpha = \beta = 90^\circ$ ,  $\gamma = 120^\circ$ . So, from the XRD Test, it is concluded the presence of Selenium particles in the Al-Se composite with hexagonal crystal structure. It self- defined that the Selenium particles are uniformly distributed in specified areas during fabrication which effects the considerable strength improvement when compared with Al-6061 material.

## 4 Conclusion

By observing all the output results from various tests, the following conclusions are drawn.

- Al6061 - Se composite is successfully fabricated using stir casting process, by varying wt.% of Se reinforcement such as 0.5, 1, and 1.5 wt.% of Se particles.
- The mechanical parameters of the selenium-reinforced Al 6061 metal matrix composite, such as tensile strength, flexural load, compression load, and Brinell hardness, have significantly improved.
- The Brinell hardness of the fabricated composites shows an increase in hardness.
- The Mechanical Properties of the Al6061-Se composite material such as Tensile Strength, Flexural & Compression strength values are increased by 32%, 29.5%, 25% respectively at 1 wt% of Selenium.
- At 1.5 wt% of Selenium, it is observed that the mechanical properties of the composite material such as the Tensile, Flexural, and compressive strength were decreased. From this, we can observe that in between 1-1.5 wt% of Selenium, the maximum strength can be achieved.

- The Selenium is also identified at three  $2\theta$  ( $39.047^\circ$ ,  $45.4383^\circ$  and  $79.915^\circ$ ) by using the Powder XRD test. It also confirms that the Selenium is in hexagonal crystal structure.
- Further research could explore the composite's behavior weight percentage between 1-1.5 of Selenium. As it can understand the trend in change of mechanical properties by an increase in wt.% of Selenium to the MMC.
- Overall, the results of this study suggest that the Al 6061 metal matrix composite reinforced with selenium is a promising material as it could improve the properties of the base material (Al-6061).

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