

Experimental Studies on Mechanical Properties of Al 7075/HEAp (Al-Cu-Co-Cr-Fe) Metal Matrix Composites and its Dry Sliding Wear Behaviour

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Abstract - The present study focuses the fabrication and characterization of an Al-7075/HEAp (Al,Cu,Co,Cr,Fe) metal matrix composites (MMCs) through stir casting, with various reinforcement contents from 3 to 9 in steps of 3%. Various tests, including tensile, compression, hardness, corrosion and impact were carried out. Dry sliding wear behaviour of composites between an EN31 disc and a smooth MMCs pin, was evaluated using a wear and friction monitor. Microstructural examination of Al-7075/HEAp metal matrix composites indicated a homogeneous distribution of reinforcements, which contributed to improved mechanical performance. Tensile testing demonstrated an increase in ultimate tensile strength as the reinforcement percentage increased, suggesting the suitability of the material for high-strength engineering applications. Hardness measurements showed a steady increase in Vickers hardness values, indicating the material's potential for demanding wear and tribological applications. The composites exhibited enhanced mechanical properties, especially with 9% reinforcement. Maximum tensile strength and modulus values are reported for 9% reinforced composites with 64% increment compared with unreinforced material. The material exhibited enhanced tribological behavior, reflected by reduced coefficient of friction (CoF) and lower wear rates.

Key Words: Al7075 alloy; Metal Matrix Composites (MMC); High-Entropy Alloy (HEA); Al-Co-Fe-Cr-Cu; Stir Casting; Mechanical Properties; Hardness; Tensile Strength; Impact Strength; Wear; Corrosion Behaviour

1.INTRODUCTION

Aluminium matrix composites (AMCs) have gained considerable attention in recent decades due to their superior combination of lightweight properties, high strength-to-weight ratio, and enhanced wear resistance, making them highly desirable for aerospace, automotive, and structural engineering applications [1]. Among the various matrix materials available, Aluminum alloy AA7075 has emerged as one of the most promising base materials due to its exceptional combination of high strength-to-weight ratio, good corrosion resistance, and excellent machinability [2]. The widespread utilization of AA7075 in critical structural applications, particularly in aerospace and automotive industries, has driven extensive research into further enhancing its properties through composite fabrication [3,4]. Metal matrix composites (MMCs) based on AA7075 have gained considerable attention due to their ability to combine the inherent advantages of the aluminum matrix with the beneficial properties of reinforcing phases [5,6]. Various reinforcement materials including silicon carbide (SiC), alumina (Al₂O₃), fly ash, and titanium diboride (TiB₂) have been extensively investigated for enhancing the properties of AA7075 matrix composites [7,8]. These studies collectively highlighted that proper reinforcement selection and processing significantly influence the mechanical strength, wear resistance, and overall performance of AA7075-based MMCs under demanding service conditions [9,10]. In recent years, high-entropy alloy (HEA) particles have emerged as a novel and promising class of reinforcement materials for aluminum matrix composites, offering unique property combinations due to their multi-principal element composition [11,12]. The tribological behavior, specifically dry sliding wear performance, of AA7075-based MMCs is critically important for applications involving moving parts and contact surfaces [13,14]. Furthermore, corrosion resistance is another critical property that determines the long-term performance and durability of AA7075-based MMCs in service environments [15,16]. The incorporation of multi-component reinforcement particles

such as Al-Cu-Cr-Co-Fe is expected to influence the corrosion behavior of the composite through the formation of protective oxide layers and modification of the electrochemical potential of the matrix [17,18]. Among the various fabrication techniques available for producing aluminum MMCs, stir casting has established itself as the most widely adopted and cost-effective method due to its simplicity, scalability, and ability to produce composites with uniform particle distribution [19,20]. Despite significant research on AA7075-based MMCs with various reinforcement materials, there remains a notable gap in the systematic investigation of multi-component Al-Cu-Cr-Co-Fe alloy reinforced AA7075 composites, particularly regarding the combined assessment of mechanical properties, dry sliding wear behavior, and corrosion resistance.

The present work aims to address this gap by fabricating AA7075/AlCoCrFeNi HEA composites through stir casting and systematically investigating the influence of HEA reinforcement content on microstructure, hardness, tensile properties, and wear behaviour. Stir casting was used to prepare AA7075 composites with HEA reinforcement. First, the aluminium alloy was melted in a furnace. The reinforcement particles were heated separately to remove moisture and help them mix better with the molten metal. The preheated particles were then slowly added into the molten aluminium while stirring. Continuous stirring helped to spread the particles evenly and reduce clustering. After proper mixing, the molten material was poured into moulds and allowed to cool and solidify.



Figure 1.1 stir casting setup

2. FABRICATION OF AA7075/HEA_p COMPOSITE

2.1 Matrix material

AA 7075 is supplied by KALPAVRIKSH STEEL INDUSTRIES Mumbai is used as a matrix material in the present investigation. Because of Aluminum is remarkable for the metal of low density and for its ability to resist corrosion due to phenomenon of passivation. Structural components made from aluminum and its alloys are vital to aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminum, at least on a weight basis are the oxides and sulphates.

Aluminum alloys with a wide range of properties are used in engineering structures. Alloy systems are classified by a number system (ANSI) or by names indicating their main alloying constituents (DIN and ISO). The strength and durability of aluminum alloys vary widely, not only as a result of the components of the specific alloys, but also as a result of heat treatments and manufacturing processes. It belongs to the 7xxx series of aluminium alloys, which are well known for their exceptional strength-to-weight ratio and are widely used in structural and engineering applications, Al7075 exhibits mechanical properties comparable to some steels, while maintaining the lightweight advantage of aluminium. The alloy is most commonly used in the T6 temper condition, which provides an optimal combination of strength and hardness through solution heat treatment followed by artificial aging.

Table 2.1: Composition of Aluminum 7075

Element	%
Si	0.4
Fe	0.9
Mn	0.3
Mg	2.9
Cu	2
Zn	6.1
Ti	0.2
Cr	0.28
Al	87.32

Table 2.2 Properties of AA 7075

Hardness	BRINELL 150
Tensile yield strength	503 MPa
Elongation at break	11%
Modulus of Elasticity	71.1 GPa
Poisson's Ratio	0.33
Machineability	70%
Density	2.81(g/cc)
Melting Temperature	477-635 (°C)

2.2 Reinforcement Material

Reinforcement is a consequence that will strengthen an organism's future behavior whenever that behavior is preceded by a specific antecedent stimulus. This strengthening effect may be measured as a higher frequency of behavior (e.g. pulling a lever more frequently), longer duration (e.g., pulling a lever for longer periods of time), greater magnitude (e.g., pulling a lever with greater force), or shortly latency (e.g., pulling a lever more quickly following the antecedent stimulus).

Al, Co, Cr, Cu and Fe powders (99.7% purity) supplied by OTTO CHEMI are used to develop the HEA reinforcement with Equi atomic composition. Density and melting point of the starting materials used for HEA preparation are given in Table 1. Al, Co, Cr, Cu, Fe HEA is prepared by passing a high-density spark into the graphite crucible containing Al, Co, Cr, Cu and Fe powders through arc melting. Al, Co, Cr, Cu, Fe HEA has higher hardness value (770 ± 10 HV) due to its nanocrystalline B2 structure. Further, the presence of Cr also leads to increased hardness due to γ phase.²² Attributable to high hardness, the Al, Co, Cr, Cu, Fe HEA alloy was chosen as reinforcement in this investigation. Since the hardness of the selected HEA is very high, a higher hardness MMC with improved wear properties is expected. The fabrication methodologies followed for Al, Co, Cr, Cu, Fe HEA preparation

in literatures are mechanical alloying and arc melting process where in the later is followed in this current study for the purpose.

Table 2.3: Properties of Reinforcement

S. NO	elements	molar mass	boiling point	melting point	density
1	Al	26.98154 g.mol ⁻¹	2467°C	660.4°C	2.7 g.cm ⁻³
2	Co	58.9332g.mol ⁻¹	2927°C	1495°C	8.9 g.cm ⁻³
3	Cr	51.966 g.mol ⁻¹	2672°C	1907°C	7.19 g.cm ⁻³
4	Cu	63.546 g.mol ⁻¹	2595°C	1083°C	8.9 g.cm ⁻³
5	Fe	55.84 g.mol ⁻¹	2861°C	1536°C	7.8 g.cm ⁻³

2.3 Fabricated HEAs Composition

Table 2.4 Fabricated HEA composition

Composition no.	Matrix % (AA7075)	Reinforcement % (All are Equi atomic)
1	100	0
2	97	3
3	94	6
4	91	9

3. RESULTS AND DISCUSSION

3.1 Hardness Studies: The Vickers hardness test is a widely used method for measuring the hardness of materials. Developed by Smith and Sandland at Vickers Ltd. in the early 1920s, it's valued for its simplicity, accuracy, and ability to test a wide range of materials, from metals to ceramics. The Vickers hardness value (HV) is then calculated as the ratio of the applied load to the surface area of the indentation. Multiple indentations were taken at different locations on each sample to ensure accuracy and repeatability, and the average hardness value was reported. This test is particularly suitable for composite materials, as it enables the assessment of micro-level hardness variations and the influence of reinforcement distribution within the matrix.

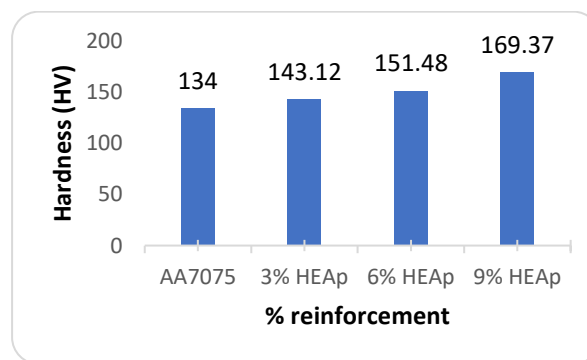


. Figure 3.1 Hardness specimens

Table 3.1 Hardness test results

s.no.	Composition	Hardness value
1	Pure Al7075	134
2	Al7075-97% Reinforcement-3%	143.12
3	Al7075-94% Reinforcement-6%	151.48
4	Al7075-91% Reinforcement-9%	169.37

Figure shows the effect of reinforcement content on the hardness of the composites. Hardness increases with the increase of the amount of reinforcement contents.



3.1 Hardness variations of composites

Hardness increases with increasing reinforcement content. Pure AA7075 shows the lowest hardness (134). With 3% and 6% reinforcement, hardness gradually improves. The highest hardness (169.37) is achieved at 9% reinforcement. Overall, more reinforcement leads to better resistance to deformation.

3.2 Tensile Behavior:

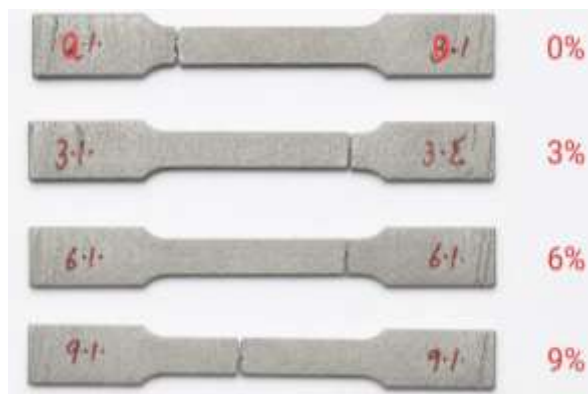


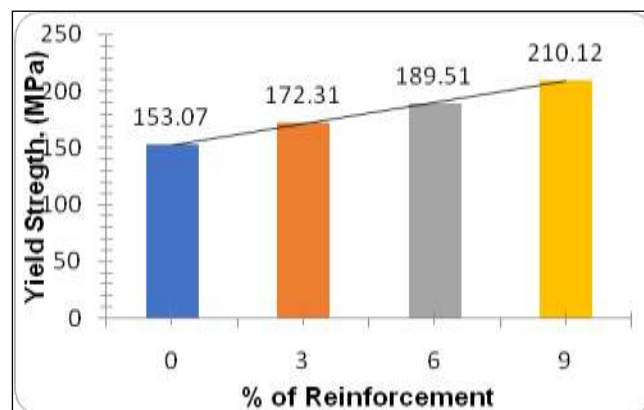
Figure 3.2 Tensile fractured specimens 3%, 6% and 9% composites

Table 3.2 Summary of Ultimate tensile strength, elongation and yield strength of composites

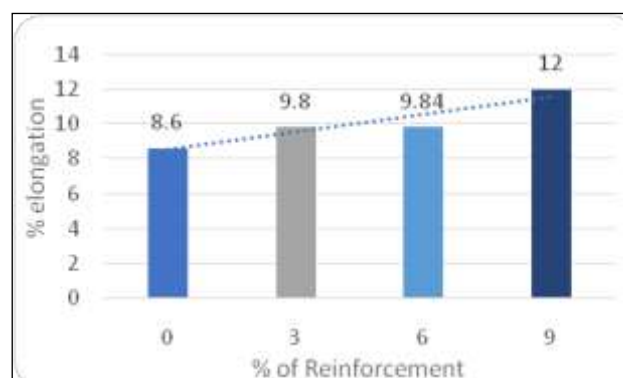
Material	Ultimate Tensile Strength MPa	%Elongation	Yield Stress MPa
AA7075	154.49	8.6	153.07
AA7075+ 3% HEAp	173.25	9.8	172.31
AA7075 +6%HEAp	190.49	9.84	189.51
AA7075 + 9% HEAp	253.7	12	252.46

Table 2.2 shows the tensile behaviour of the alloy and the composites with reinforcements between 3 and 9%. Composites show improved strength properties compared to the base matrix. Increased reinforcement content enhances the strength properties further. The tensile properties of composites found to be increasing with reinforcement content of the composites.

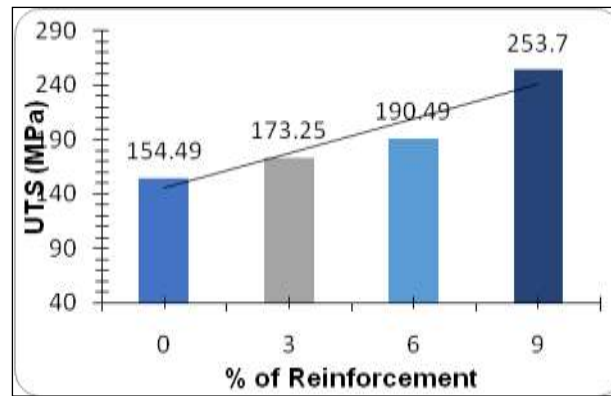
The results show a clear improvement in mechanical properties with increasing HEA reinforcement. The base AA7075 alloy has the lowest values, with an ultimate tensile strength of 154.49 MPa, yield strength of 153.07 MPa, and 8.6% elongation.



3.2 Effect of reinforcement content on Yield Strength



3.3 Effect of reinforcement content on % elongation



3.4 Effect of reinforcement content on Ultimate Tensile Strength

With 3% HEA reinforcement, both strength and ductility increase, indicating better load-bearing capacity and improved material behavior. At 6% reinforcement, there is a further rise in tensile and yield strength, along with a slight increase in elongation. The 9% HEA composite shows the highest performance, with a tensile strength of 253.7 MPa, yield strength of 252.46 MPa, and 12% elongation. This indicates significant strengthening along with improved ductility.

3.3 Impact Strength (Charpy)



Figure 3.3 Impact fractured specimens 0%, 3%, 6% and 9% composites

Table 3.3: Impact test results

Material	Impact Strength (Joules)
AA7075	0.4169
AA7075 + 3% HEAp	0.7654
AA7075 + 6% HEAp	1.0495
AA7075 + 9% HEAp	1.2400

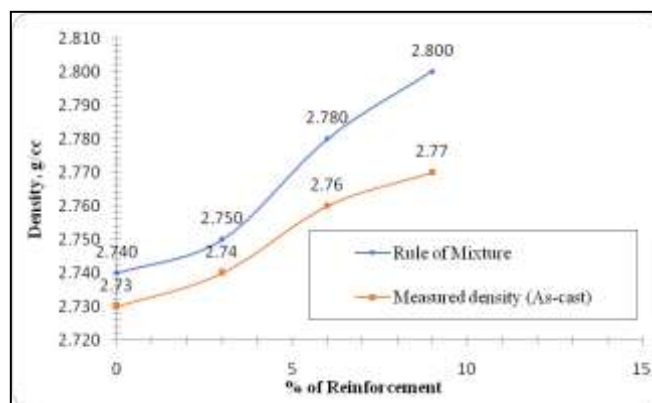
The results show a steady increase in impact strength with the addition of HEA reinforcement. The base AA7075 alloy has the lowest impact strength (0.4169 J), indicating limited ability to absorb energy during sudden loading. With 3% HEA, the impact strength increases to 0.7654 J, showing improved toughness. At 6% reinforcement, it further rises to 1.0495 J, indicating better energy absorption capability. The 9% HEA composite exhibits the highest impact strength (1.2400 J), demonstrating significantly enhanced toughness and resistance to fracture.

3.4 Density of Composites:

The density test determines the mass of a substance per unit volume. Actual method is using Archimedes' principle, where the object's buoyant force in a fluid is used to calculate its density. In a typical setup, you measure the object's mass, submerge tina fluid, measure the volume of displaced fluid, and then calculate its density using the formula: $\text{Density} = \text{Mass} / \text{Volume}$. And theoretical density is calculated using rule of mixtures. The rule of mixtures estimates the density of a composite material by considering the densities of its constituent elements and their respective volume fractions.

Table 3.4 Density study results

S.NO	Composition	Theoretical density	Actual density	Relative density
1	Pure Al7075	2.81	2.8	0.01
2	Al7075-97% Reinforcement3%	2.93	2.85	0.08
3	Al7075-94% Reinforcement6%	3.06	2.9	0.11
4	Al7075-91% Reinforcement9%	3.19	3.02	0.17



3.5 Density variations of composites

The results show that both theoretical and actual density increase with higher reinforcement content. Pure AA7075 has the lowest density, while the composite with 9% reinforcement shows the highest values, due to the addition of denser reinforcement particles.

However, the difference between theoretical and actual density also increases as reinforcement increases. This is reflected in the rising relative density difference (from 0.01 to 0.17), indicating the presence of porosity or casting defects in higher reinforcement samples.

3.5 Wear Test:

The wear performance of AA7075 composites with different reinforcement contents (0%, 3%, 6%, and 9%) was evaluated under varying conditions of sliding velocity, applied load, and sliding distance. The results reveal clear trends in how reinforcement and test parameters influence both wear and friction force.

The results show a clear improvement in wear resistance with increasing reinforcement content. The 0% sample has the highest wear and unstable friction, indicating poor performance. With 3% reinforcement, wear slightly decreases, but results are still inconsistent. The 6% composite shows better and more stable wear resistance, indicating improved load distribution. The 9% reinforced sample performs the best, with the lowest wear and more stable friction values.

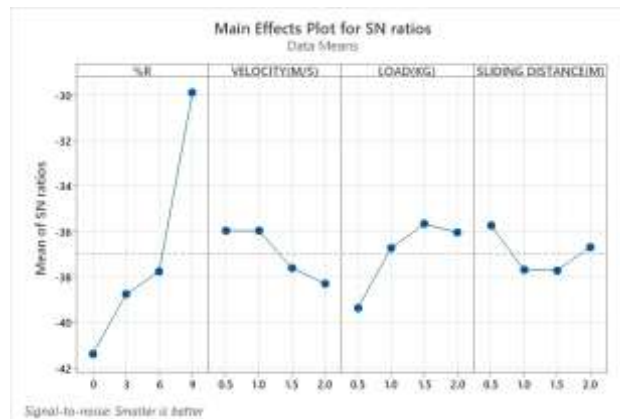


Figure 3.4 Wear Test Specimens

Table 3.5 Wear Test Results

s.no	%R	Velocity (m/s)	Load (kg)	Sliding distance(m)	Wear	Friction force
1	0	0.5	0.5	0.5	165.37	65.41
2	0	1	1	1	190.64	10.65
3	0	1.5	1.5	1.5	95.65	84.82
4	0	2	2	2	175.39	15.38
5	3	0.5	1	1.5	120.64	11.59
6	3	1	0.5	2	85.31	63.8
7	3	1.5	2	0.5	125.89	6.21
8	3	2	1.5	1	140.56	1.87
9	6	0.5	1.5	2	85.23	51.63
10	6	1	2	1.5	95.12	30.97
11	6	1.5	0.5	1	175.64	7.19
12	6	2	1	0.5	80.66	14.1
13	9	0.5	2	1	25.65	14.28
14	9	1	1.5	0.5	30.32	4.95
15	9	1.5	1	2	45.82	11.39
16	9	2	0.5	1.5	90.25	6.36

3.5.1 Wear SN ratios: The main effects plot for S/N ratios provides insight into how different parameters influence wear performance under the “smaller is better” criterion. From the graph, it is clear that the reinforcementpercentage(%R) has the most significant impact. As the reinforcement increases from 0% to 9%, the S/N ratio improves considerably (moves upward), indicating a strong reduction in wear. This confirms that higher reinforcement content enhances the material’s resistance to wear. The plot shows that reinforcement (%) has the greatest effect on wear. Increasing it to 9% gives the best performance (lowest wear). Lower velocity and shorter sliding distance help reduce wear, while a moderate load (~1.5 kg) gives optimal results. the weight percentage of reinforcement shows a moderate influence, where increasing the percentage beyond an optimum level to a slight decrease in S/N ratio, possibly due to particle clustering or weak bonding within the matrix. The load or sliding distance parameter exhibits some variation, with moderate levels providing better results compared to extreme values, as higher loads may increase wear or damage.



3.6 Wear SN ratios graph

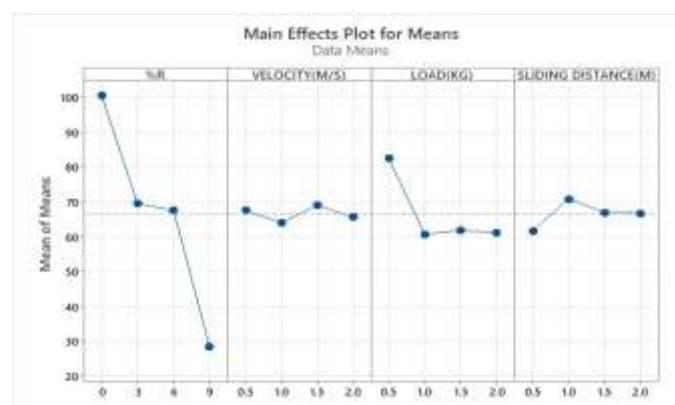
3.5.2 Friction Main Effects Plot for Means

The “Main Effects Plot for Means” illustrates how each of the four parameters influences the average wear obtained during the test. By observing how steep or flat each line appears, it becomes easier to identify which factors play a major role and which ones have only a minor effect. Among all the parameters, the percentage of reinforcement (%R) has the strongest influence. The mean wear value decreases sharply as the reinforcement increases from 0% to 9%. This clear downward trend shows that adding more reinforcement significantly improves wear resistance, resulting in lower material loss. The plot shows that reinforcement (%) has the strongest effect on wear. As reinforcement increases from 0% to 9%, the mean wear value drops sharply, indicating a significant improvement in wear resistance.

For velocity, the variation is small, but slightly lower wear is observed around 1 m/s, suggesting moderate speed is preferable.

In the case of load, wear is highest at low load (0.5 kg) and decreases at higher loads, showing better performance at moderate to higher loads.

For sliding distance, wear slightly increases at 1 m and then stabilizes, indicating a minor effect compared to other parameters.



3.7 Graph of Friction

3.6 Corrosion Test:

The degradation behaviour of AA7075 and its reinforced composites was studied in a 0.5 M solution for immersion times ranging from 1 to 4 hours. The results, evaluated through weight loss measurements, clearly show the effect of both reinforcement content and exposure time on material

performance. The best results are obtained for the composite with 9% reinforcement. This sample consistently shows the lowest weight loss across all time intervals, indicating superior resistance to material loss. The improved behaviour can be linked to the higher amount of reinforcement, which likely acts as a protective barrier and enhances the overall strength and durability of the composite. In all cases, weight loss increases with time, which is expected due to longer exposure to the solution. However, the rate at which the material degrades decreases as the reinforcement percentage increases. This clearly shows that reinforcement plays an important role in improving resistance to degradation. The results indicate that increasing the reinforcement content enhances the performance of AA7075 composites in a 0.5 M environment. Among the samples studied, the 9% reinforced composite demonstrates the best resistance, making it a suitable choice for applications where durability and resistance to material loss are important

Table 3.6 Corrosion Test results

s.no	Molarity	Reinforcement%	Initial weight	Final weight	Difference	Time (Hrs)
1	0.5M	0	1.6031	1.3232	0.2799	1
2	0.5M	0	1.6481	1.2525	0.3956	2
3	0.5M	0	1.5252	1.0356	0.4896	3
4	0.5M	0	1.3251	0.8345	0.4906	4
5	0.5M	3	1.6146	1.3614	0.2532	1
6	0.5M	3	1.5544	1.1895	0.3649	2
7	0.5M	3	1.6614	1.2153	0.4461	3
8	0.5M	3	1.3614	0.8825	0.4789	4
9	0.5M	6	1.6173	1.4209	0.1964	1
10	0.5M	6	1.3693	1.0832	0.2861	2
11	0.5M	6	1.4687	1.0373	0.4314	3
12	0.5M	6	1.4817	1.0351	0.4466	4
13	0.5M	9	1.6516	1.4817	0.1699	1
14	0.5M	9	1.6635	1.4247	0.2388	2
15	0.5M	9	1.6332	1.2646	0.3686	3
16	0.5M	9	1.4209	1.0078	0.4131	4

CONCLUSION:

1. The results clearly indicate that incorporating HEA particles into Al7075 improves its overall properties. The experimental density values are very close to the theoretical ones, which suggests that the composites were produced with good quality and strong bonding between the matrix and reinforcement.
2. As the percentage of reinforcement increases, the hardness of the material also increases, showing better resistance to indentation and wear. In the same way, tensile strength improves with higher reinforcement content, meaning the composites can handle greater applied loads than the base alloy.
3. The impact strength does not follow a clear trend, which means the addition of reinforcement does not significantly enhance the material's ability to absorb sudden loads.
4. The wear test results highlight that higher reinforcement leads to lower wear. Among all the samples, the 9% HEA composite shows the least wear, indicating the best wear resistance.
5. As the reinforcement percentage increases from 3% to 9%, the weight loss gradually decreases, demonstrating enhanced resistance to material degradation. Among all the specimens, the 9% HEA composite exhibits the lowest weight loss across all time intervals, indicating superior corrosion performance. The study confirms that increasing HEA reinforcement is an effective way to enhance

the corrosion resistance of Al7075, making it more suitable for applications in aggressive environments.

In summary, increasing the reinforcement percentage has the strongest effect on improving mechanical and wear properties, with 9% reinforcement giving the most effective results.

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It is indeed a matter of great pleasure and proud privilege to be able to present this project on “Experimental Studies on Mechanical Properties of Al 7075/HEAp (Al-Cu-Co-Cr-Fe) Metal Matrix Composites and its Dry Sliding Wear Behavior Particles Subtitle: Fabricated through Stir casting Method”. We would like to take this opportunity to express our respect and deep gratitude to our guide Prof. Dr. K. PRAVEEN KUMAR for giving all necessary guidance required for this project, apart from being constant source of inspiration and motivation. I would like to thank the Department of Mechanical Engineering, RVR & JC College of Engineering, Guntur, Andhra Pradesh, for providing the facilities and support for this research work.

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