

Microstructural Characterisation and Analysis of Mechanical Behaviour of Hybrid Aa 7075/7178 Fabricated Using Die Casting Technique

Anuj Bindra^{1,*}, S. Gajanana², Devesh kumar³

Abstract

AA are being increasingly used in the field of structural engineering owing to their desirable mechanical properties coupled with their recyclable and sustainable nature, thus contributing significantly towards reduction of carbon footprints and development of circular economy. Till date numerous research projects have been prompted to investigate the structural performance of aluminum alloy structures and develop alternatives with enhanced performance parameters. AA 7xxx (Al-Zn-Mg-Cu) are being widely used in variety of engineering services owing to their high specific strength, hardness, corrosion performance, and machining performance. AA 7075 as well as AA 7178 remains dominant in aerospace industry, compared to their steel counter parts. In this research work, a hybrid blend of AA 7075/7178 was fabricated using Die casting technique to get an optimum composition that yields high strength material for structural purposes. These samples were subjected to mechanical testing such as Hardness, Ultimate tensile strength, percentage elongation, yield strength. Analysis of micro structural behavior and morphology such as grain refinement, grain boundary network was undertaken using scanning electron microscopic images with 100x and 500x magnification. The microstructure images of AA7075/7178 consists of Interdentric network of particles of CuAl_2 , NiAl_3 and Mg_2Si which indicates that the material has limited hardness and excellent tensile strength. Results indicated that the Hybrid blend with composition as Zn – 7.3 %, Mg – 2.1 %, Cr – 0.18 %, Cu – 2.4 %, Si – 0.4 %, Fe – 0.5 %, Ti – 0.2 %, Mn – 0.3 % exhibited maximum tensile strength and moderate hardness as compared with their base materials. Hence, it is an urgent requirement to develop next generation AA 7xxx alloys with enhanced strength, toughness and damage to resistance.

Keywords: Die Casting, AA 7075, AA7178, Tensile Testing, Microstructural Characterisation

INTRODUCTION

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Aluminium alloys are versatile materials that have been used in various engineering applications for many decades, including aerospace [1], automotive [2], and marine engineering. The production of aluminium alloy has been steadily increasing over the past twenty years (from 2002 to 2022). The 7xxx series of aluminium alloys are chosen for the construction of upper wing skins, stringers, and horizontal and vertical stabilizers because they exhibit greater strength than other classes of aluminium alloys. The compressive strength and the fatigue resistance are the critical parameters in the design of upper wing structural components. Excellent strength-to-weight ratio, superior electrical and thermal conductivities, non-magnetic properties, ease of fabrication, and

exceptional resistance to corrosion characterize aluminum and its alloys. The addition of alloys including silicon, magnesium, iron, and manganese improves the material's mechanical properties and strength-to-weight ratio

7xxx AA (Al-Zn-Mg-Cu) have been widely used in a variety of engineering services owing to their high specific strength, hardness, corrosion performance, and machining performance [3-5]. AA7075 have proven to be more susceptible to embrittlement than any other aluminium dual alloy, while also providing superior corrosion resistance than the 2000 series of aluminium alloys. Various studies in aerospace industry have shown that AA7075 are the only aluminium alloys that can survive high-stress structural applications, which has resulted in a major rise in their use for aircraft bodies and engines [6-8]. AA 7075, a representative of this particular category, remains their dominance in aerospace industry [9-10] and also, emerges progressively in automotive sector [11]. Compared to their steel counterparts, the application of high strength AAs could achieve 40% reduction in the body weight of the structure [12-13].

In engineering applications, aluminium is the lightest and most nonreactive metal [14]. The strength and durability of aluminium and its alloys in engineering applications play an important role. Due to its lightweight, it offers advantage in applications, but lower strength is a crucial limitation. The alloying of aluminium largely paves the way for obtaining the desired strength coupled with light weight. Data also proves that aluminium alloys are widely used in various products and markets such as aerospace, marine industries etc. [15]. In the field of aviation, the weight of the structure plays an important role as far as fuel consumption is concerned. Iron-based alloys are not as popular as aluminum alloys due to their low strength-to-weight ratio [16]. Till date, researchers have investigated many different alloying elements to improve various properties of aluminium including Mg, Cu, Zn, Si, etc. and reported their outcomes.

The importance of aluminium-zinc alloys such as AA7075, AA7178 have been identified in many applications in recent industries namely aviation, aerospace, and military applications. Due to the limitations of some properties of these alloys, scientists have been attempting to improve their performance by preparing blends as well as incorporating one or more unique reinforcing particles into metals, significantly improving the fabricated metal matrix composition These Aluminium metal matrix hybrids have recently attracted great interests in engineering applications owing to their lightweight and distinct mechanical properties.

The addition of zinc to aluminium alloy has been found to have varying effects on its mechanical properties. The presence of zinc can improve the strength and hardness of the aluminium-based alloy, leading to higher yield and tensile strength [17–21]. Additionally, zinc can also contribute to the development of intermetallic compounds that further enhance the alloy's mechanical properties [22-23]. However, it should be noted that at higher concentrations, zinc may not significantly increase the mechanical properties of the aluminium alloy, but it can greatly reduce its plasticity [24]. This means that while zinc can improve the strength and hardness of the aluminium alloy, excessive amounts of zinc can make the alloy less malleable and ductile. Furthermore, the addition of zinc to the aluminium alloy can also improve its corrosion resistance [25-26]. This is due to the formation of a protective oxide layer on the surface of the alloy, which can help to prevent or slow down the corrosion process. The combination of zinc and aluminium in an alloy can result in a solid solution strengthening effect, where the zinc atoms occupy interstitial sites in the aluminium crystal lattice, leading to increased strength and hardness [27]. Study of the corrosion resistance behaviour of Al–Zn alloy concludes that for a hypoeutectic Al–Zn alloy higher corrosion resistance was found for finer dendritic structures than courser dendritic structure [28]. Investigations of electrochemical and tensile properties of Al alloy finds that 1.5 % Zn content has the highest tensile strength among the compositions investigated [29]. The addition of Zn could also reduce the stress corrosion cracking of Al alloy [30]. Because AA 7075 alloy is one of the strongest aluminium alloys available, hence it is used in high-stress situations. Its Cu

component also increases the alloy's sensitivity to corrosion, which makes the material more durable and practical. Its strong resistance to fatigue and good corrosion resistance make it a robust material suitable for use in severe settings as well as high-stress applications in structural industry especially aviation.

Due to their exceptional strength, both aluminum and carbon fiber are being utilized extensively in a variety of structural sectors. With its remarkable strength-to-weight ratio, carbon fiber surpasses aluminum in strength per unit weight. It provides increased adaptability, toughness, and resilience to adverse environments. Aluminum, on the other hand, shines out due to its corrosion resistance, lightweight nature, and adaptability. But, there are certain situations where aluminum works better than carbon fiber, even with all of carbon fiber's benefits. Due to the complex engineering, labour-intensive manufacturing process, and requirement for specially made molds for every component, carbon fiber is more expensive than other materials. Aluminum alloys are probably used in places that will be exposed to a lot of heat because carbon fiber can break down in these kinds of conditions.

The choice between the two materials ultimately homes down to the particular needs of the project or the sector where these will be utilised. Both materials have their own advantages and applications. Aluminum is a cost-effective substitute when a solution that is inexpensive is needed. Despite carbon fiber's higher price, aluminum is still a more cost-effective option due to its diverse qualities and low cost. Material costs are still a major consideration in the design and construction of aircraft as well as in upkeep and repair. As a result, there are situations in which it could seem advantageous to choose a very similar but less expensive substitute material.

It's not enough to compare the numbers of aluminum and carbon fiber to make an informed decision. The best metal ultimately depends on how well the material fits the requirements of the project. For jobs when performance is crucial and stakes are high, carbon fiber is the star whereas, aluminum is the greatest option for everything else when we need a dependable and affordable material.

Depending on the intended use, aluminum is available in a variety of alloys with different characteristics and qualities. We must take into account the qualities needed for the intended applications while selecting an alloy. The most popular and crucial factors are strength, corrosion resistance and conductivity. While there are other aluminum alloys that can be used in place of aluminum alloy 7075, AA 6061 is the most widely used. Among the most popular alloy types with numerous uses in the aircraft and structural industries are aluminum alloys 7075 and 6061.

It is challenging to distinguish the compositional changes between aluminum alloys 6061 and 7075. The same alloy agents, such as silicon, copper, iron, zinc, magnesium, titanium, manganese, and chromium, are present in both grades. The amounts of each agent in the two aluminum materials—rather than the component make-up—are what really set the two alloys apart. AA 6061 is widely regarded as an extremely adaptable aluminum material despite its lower strength. The 6061 alloy has better welding and workability qualities than the majority of other alloys. A frequent option for alloys that require a high degree of adaptability and ease of welding and machining is AA 6061. Its sufficient strength, formability, weldability, machinability, and corrosion resistance make it one of the most widely used aluminum alloys after AA7075 in the aviation structural industry.

EXPERIMENTAL PROCEDURES

Casting Process

Currently, industry strives for a state in which the number of internal casting defects must be reduced to close to zero (zero defect approach) in order to improve the mechanical qualities of the products. For complex shapes, metal casting is one of the best manufacturing processes available since it produces improved mechanical qualities. It's also one of the easier and least expensive methods. The popularity of Aluminium Alloys in automobile & aerospace industries is due to their excellent strength to weight ratio, casting characteristics and mechanical properties such as wear resistance, hardness, compressive strength, ultimate tensile strength, high thermal conductivity & high corrosion resistant.

Gravity die casting process is one of the best continuous casting process for non-ferrous alloys with high fluidity and low fusion temperature and is commonly used for aluminium alloys, magnesium alloys, and copper alloys etc [31]. This kind of permanent mold casting involves pouring molten metal at atmospheric pressure into a mold while it is vertically positioned. Before the molten metal is put inside, the two halves of the mold are sealed. The mould halves are opened to release the cast component once the melt has solidified. One benefit of this manufacturing process is that there is less gas or trapped air inside the mold. Large, thick wall components and components with a lot of detail work well with this technique. Components manufactured with this process are typically of complex geometry.

Over the past few decades, zinc - aluminium alloys have attracted great research interest due to their excellent castability, machinability and sliding wear resistance, making them attractive alternative to their conventional counterparts such as cast iron, aluminium alloys and copper-based alloys in various engineering applications. In addition, zinc –aluminum alloys' low melting point and low energy consumption make them particularly well-suited for the die casting industry [32].

Materials

In this present work, the samples of hybrid metal matrix alloy of AA 7075/7178 have been prepared by Die casting process. The standard compositions of AA7075 and AA7178 have been prescribed in Table 1 and 2. The composition range of AA 7075 and AA 7178 shown below gives out a similarity in the alloying elements that include Zn, Cu, Mg, Cr. Hence, in order to develop a model, the lowest and highest percentages of these alloying elements have been considered for preparation of optimum composition of Hybrid blend. The proposed composition of hybrid AA7075/AA7178 has been given in Table-3.

Table 1. Composition of Al 7075.

Component	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti	Al
Amount (wt. %)	6.3-7.3	2.4-3.1	1.6-2.4	0.18-0.29	0.4	0.5	0.3	0.2	85.51 - 88.12

Table 2. Composition of Al 7178.

Component	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti	Al
Amount (wt. %)	5.1-6.1	2.1-2.9	1.2-2	0.18-0.28	0.4	0.5	0.3	0.2	87.32 - 90.02

Table 3. Proposed composition of hybrid Al 7(075+178).

Component	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti	Al
Amount (wt. %)	5.1 - 7.3	2.1 - 3.1	1.2 - 2.4	0.18-0.29	0.4	0.5	0.3	0.2	87.32 - 88.12

From the above Tables, it is evident that we have considered two levels of minimum and maximum percentages of four primary constituent parameters namely Zn, Cu, Cr, Mg. The model has been developed with four parameters with two levels resulting in eight trails. These samples have been prepared using Die casting process with a die of cast iron metal having a cylindrical shape. AA 7075/AA 7178 have been melted in frequency-based induction crucible furnace up to 700°C to 750°C and poured into the die. The molten metal enters into die under the force of gravity and casts are taken out post solidification. The prepared die has a diameter of 25mm and length as 250mm. Table-4 shows composition of elements (in percentages) for preparation of specimens.

However, the calculation of the mean composition of hybrid metal matrix alloy of AA7075/AA7178 has been shown in Table 5.

Table 4. Composition of Elements for preparation of Specimens (%)

Trail	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti
1	5.1	2.1	1.2	0.18	0.4	0.5	0.3	0.2
2	5.1	2.1	2.4	0.29	0.4	0.5	0.3	0.2
3	5.1	3.1	1.2	0.29	0.4	0.5	0.3	0.2
4	5.1	3.1	2.4	0.18	0.4	0.5	0.3	0.2
5	7.3	3.1	1.2	0.18	0.4	0.5	0.3	0.2
6	7.3	3.1	2.4	0.29	0.4	0.5	0.3	0.2
7	7.3	2.1	1.2	0.29	0.4	0.5	0.3	0.2
8	7.3	2.1	2.4	0.18	0.4	0.5	0.3	0.2

Table 5. Calculation of the mean composition of Al 7075 + 7178 (in grams).

Trail	Zn	Mg	Cu	Cr	Si	Fe	Mn	Ti	Al
1	51	21	12	1.8	4	5	3	2	900.2
2	51	21	24	2.9	4	5	3	2	887.1
3	51	31	12	2.9	4	5	3	2	889.1
4	51	31	24	1.8	4	5	3	2	874.2
5	73	31	12	1.8	4	5	3	2	868.2
6	73	31	24	2.9	4	5	3	2	855.1
7	73	21	12	2.9	4	5	3	2	877.1
8	73	21	24	1.8	4	5	3	2	866.2

The processing of casts and specimens prepared thereof using the methodology of Die casting have been shown in Figure 1(a-d).

CHARACTERISATION AND BEHAVIOUR ANALYSIS

Mechanical Properties

Aluminium alloys exhibits a high strength to weight ratio, and is widely used in construction materials and aerospace materials such as wings and fuselage. Because of the great strength and light weight of these alloys, it is also used in many industrial fields. Tensile testing is a destructive test method used to determine the metallic material's tensile strength, yield strength, and ductility. It gauges how far a composite or plastic specimen stretches or elongates before breaking, as well as the force needed to break it. A controlled force is applied on the sample and its elongation is measured which helps in obtaining several material properties like stress and strain. The test properties include Young's modulus, poissons ratio, ultimate tensile strength etc. are performed as per ASTM standards. Previous studies have performed tensile tests to determine the ductility of the materials [33-34].

In this present study, tensile testing of the prepared blend of aluminium alloys has been performed to determine the true stress and strain values of the prepared material as well as its ductility. The tensile

testing has been performed as per ASTM E8 standards. The equipment used for tensile testing is MCS Mechatronics and Testing Machine (UTE 20T). The specifications being force capacity: 100n–100 kn with maximum force at full speed: 25 kN.

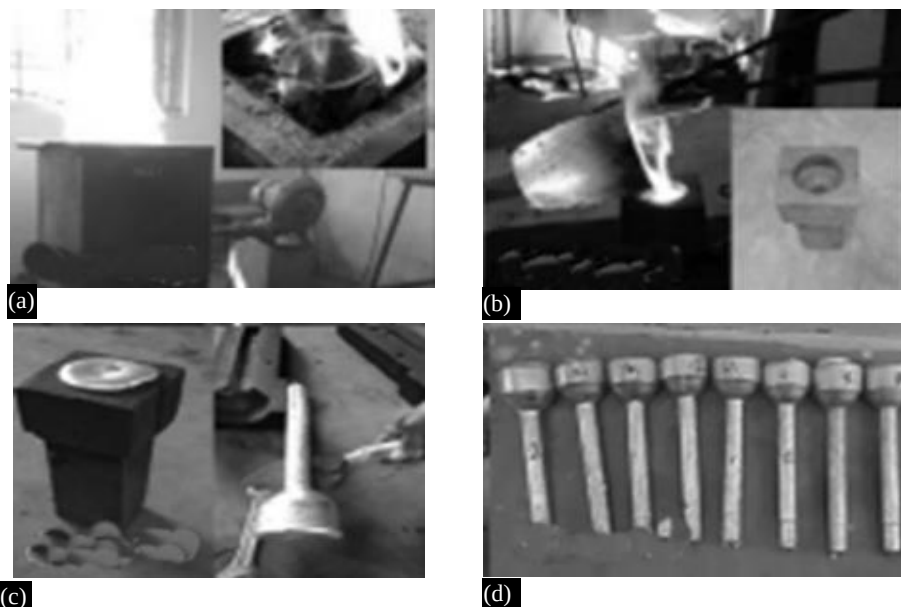


Figure 1. Die casting process and casting specimens.

Moreover, the Brinell hardness test method is used to determine micro hardness of alloys prepared in accordance with ASTM E10 standards using a Rockwell cum Brinell hardness tester. The test was performed using a carbide ball indenter of diameter 5 mm with the plunging load of 250 kgf. All the tests were repeated for 3 iterations to compute the average values.

Microstructure Characterisation

The performance of aluminium alloys is closely related to their microstructural characteristics, showing different softening mechanisms such as recrystallisation under different thermal deformation conditions. These mechanisms, in turn, have different effects on the grain size and its distribution, ultimately influencing the performance and uniformity of formed parts. Hence, it is of great guiding significance to master the microstructure evolution law of aluminium alloys during hot deformation for precisely regulating deformation parameters and manufacturing products those meeting performance requirements [35].

The physical characteristics of a material, such as its strength, toughness, ductility, hardness, corrosion resistance, behavior at high and low temperatures, or wear resistance, can be significantly influenced by its microstructure. These characteristics then determine how these materials are used in industrial processes. A material's mechanical and physical qualities are essentially determined by the various flaws that are either present or absent in the structure of the material's microstructure. Although these flaws can appear in many different ways, pores are the most common type. Even if these pores are crucial in defining a material's properties, so is the material's composition. In fact, for many materials, different phases can exist at the same time. These phases have different properties and if managed correctly, can prevent the fracture of the material. The experimental setup used for microstructure analysis in our Equipment is Make: Meta scope, Etchant used: Keller's Reagent, Test method : ASTM E407 & ASM Metallic Handbook Volume –IX, Magnification : 100X and 500X.

RESULTS AND DISCUSSIONS

Mechanical Properties

Tensile test

Figure 2 demonstrates the dimensions of specimen used for tensile testing.

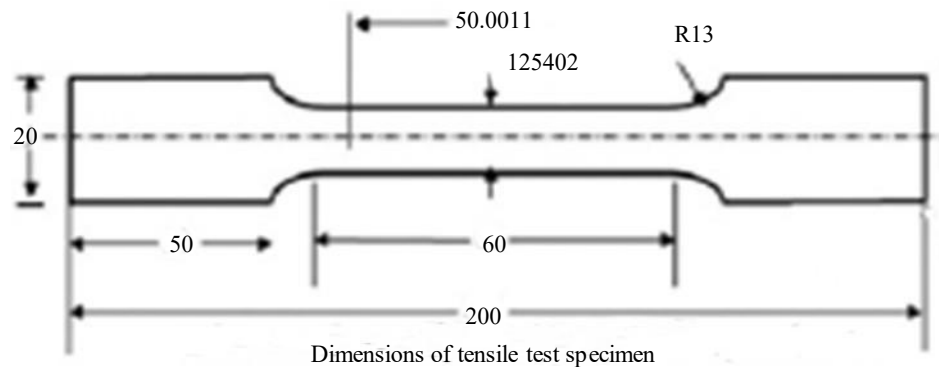


Figure 2. Specimen dimension for tensile testing.

The results of tensile observations have been shown in Table 6 below.

Table 6. Tensile test observations.

Specimen	Yield stress (MPa)	Ultimate tensile strength (MPa)
Al (7075+7178) -1	182.6	216.90
Al (7075+7178) -2	171.8	186.34
Al (7075+7178) -3	151.4	196.26
Al (7075+7178) -4	168.2	201.23
Al (7075+7178) -5	179.8	208.69
Al (7075+7178) -6	179.8	222.90
Al (7075+7178) -7	151.7	209.56
Al (7075+7178) -8	180.8	225.36

It is evident from the results that the highest tensile strength of hybrid metal matrix AA 7075/7178 can be observed for the sample 8 i.e., Tensile strength of 225.36 MPa with following composition of elements: Zn – 7.3 %, Mg – 2.1 %, Cr – 0.18 %, Cu – 2.4 %, Si – 0.4 %, Fe – 0.5 %, Ti – 0.2 %, Mn – 0.3 %. On comparison of results, the tensile Strength of AA 7075 and AA 7178 is less than the casted specimen of hybrid metal matrix i.e., AA 7075/7178. The graphical representation of load vs displacement for the prepared samples have also been shown in Figure 3.

Hardness test

The results of the Brinell hardness test have been shown in below at Table7.

Microstructure behaviour

On evaluation of the microstructure of casted samples, it has come to light that they consists of fine dendritic structures with precipitation of Zn and Mg in higher phases a long with presence of other inter metallic compounds. It is interpreted that the sample S1 is exhibiting a well-defined linear elongation deformation up to 20kN of load and undergone a displacement of 30mm. The yield stress of sample S1 is higher out of all samples, which explains the presence of higher percentage of Aluminium. The sample S8 reveals a highly non-linear elastic deformation nature because of higher amount of copper content and coarse grain structure. S6 sample stands next to S8 sample with respect to ultimate tensile strength; however yield strength is decreased because of higher amount of Magnesium content. The analysis suggests that sample S8 is preferable because of its high yield and tensile strengths. Sample S8 shows a clear coarse dendritic structure with higher tensile in nature which may be preferable for industrial applications. Figure 4(a-h) below represents the microstructure analysis of the casted samples.

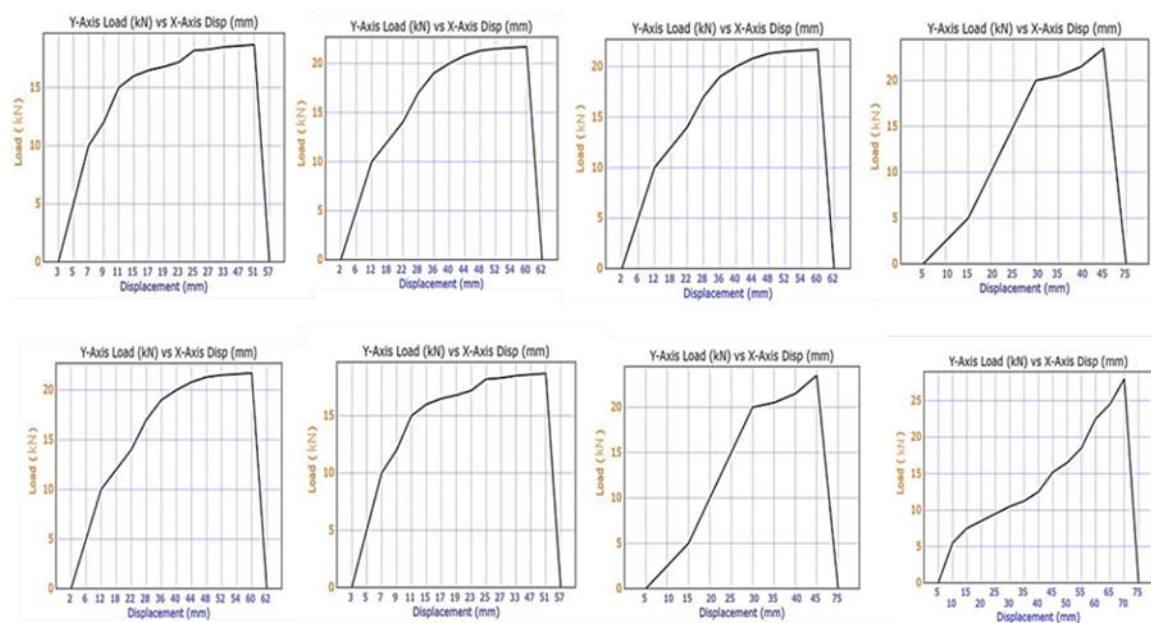


Figure 3. Load vs displacement graphs for the samples.

Table 7. Hardness test observations.

Al (7075+7178)	Hardness (BHN)					
Specimen 1	76.2	85	82	80	81	Avg: 80.84
Specimen 2	95	102	102	101.6	102.1	Avg: 100.54
Specimen 3	95	97.1	95.62	94.75	95.66	Avg: 95.52
Specimen 4	88	85	86	86.5	86.4	Avg: 86.38
Specimen 5	81	88	84	89	83	Avg: 85.00
Specimen 6	83	80	81	83.6	81	Avg: 81.72
Specimen 7	91	92	90	91	90	Avg: 91.00
Specimen 8	88	89	83	84	86	Avg: 86.00

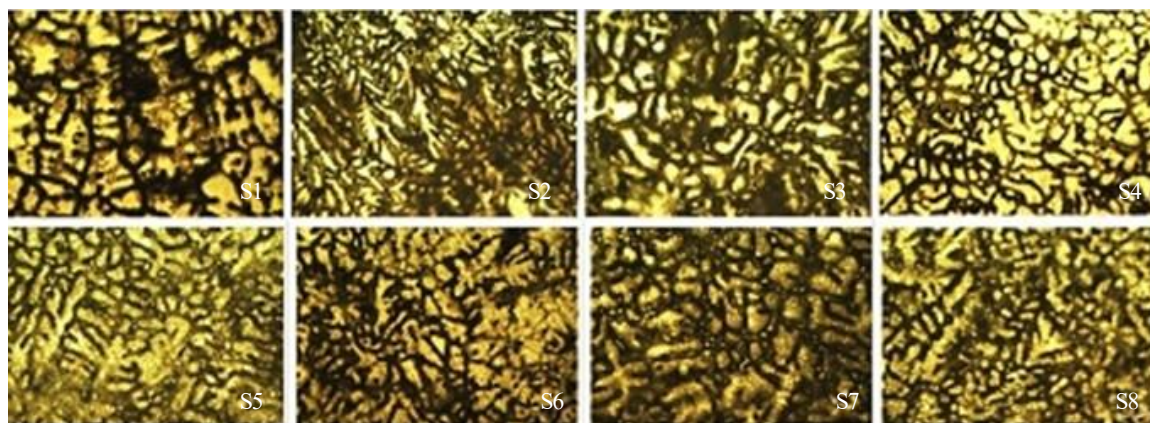


Figure 4. (a-h): Microstructure of the samples

CONCLUSION

This research aimed to prepare a blend of two most commonly used AA in the aerospace industry dealing with structural applications. High performance aluminium alloys with excellent mechanical and machining properties are used to produce a hybrid blend. AA7075 and AA7178 alloys have been die casted to get an optimum composition of hybrid AA metal matrix alloy 7(075+178) with improved strength and enhanced comprehensive properties. The composition of four alloying elements was varied

namely copper, magnesium, zinc and chromium, whereas the remaining alloying elements were kept in a fixed proportion. Two levels of minimum and maximum percentages of the selected parameters have been selected to develop the samples. The specific outcome of the present research work is as follows.

- a. The variations in the alloying elements lead to composition of a hybrid blend with enhanced tensile strength than the commercially available AA 7075 and Al 7178 alloys. The sample S8 of hybrid blended alloy produced a highest tensile strength of 225.36MPa. The alloy contains zinc and chromium as larger content giving higher load bearing effect than other formations.
- b. Similar improvements were observed in hardness results. The sample S2 of hybrid blend results into higher values of hardness. This configuration contains copper and chromium as larger content giving higher load bearing effect than other formations and also, when compared with AA 7075 and AA 7178.
- c. The microstructure of hybrid blend shows that they consists of fine dendritic structures with precipitation of Zn and Mg in higher phases along with presence of other inter metallic compounds. The analysis suggests that sample S8 is preferable because of its high yield and tensile strengths. In addition, it shows a clear coarse dendritic structure with higher tensile in nature which may be preferable for industrial applications.
- d. Thus, the research revealed that Aluminium metal matrix alloy of AA 7075/7178 can be successfully fabricated by using the process of Die casting. The tensile testing provides multiple applications and facilitates to determine the various aspects of mechanical behaviour such as yield strength, tensile strength, with different categories of ductile and brittle materials. Also, appreciable improvements in mechanical properties and microstructural behaviour have been observed in the prepared hybrid blend AA 7075/7178 as compared with their base materials i.e., AA 7075 & AA 7178.
- e. The structural aluminum alloys market is expected to increase in the future due to the continuous focus on sustainability and the circular economy. Comprehensive research into aluminium alloy structures with various section profiles subjected to varied loading scenarios is being continuously conducted, to verify their structural response, assess the applicability of codified design provisions and formulate improved design methods leading to an appreciable amount of applications in different sectors like aerospace, defence, military, and other industrial applications. Therefore, the hybrid metal matrix blend, with enhanced comprehensive properties, will definitely serve as a working material in aerospace, automotive and structural applications where weight and strength is of concern.

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Authors' Contributions

Author 1: Col Anuj Bindra : Conducted experimentation, collected data, performed analysis and validation and wrote the research article.

Author 2: Dr. S. Gajanana: Made a substantial contribution to the concept of design of the article, the acquisition, analysis, or interpretation of data for the article. Revised the drafted article critically for important intellectual content.

Author 3: Dr. Devesh Kumar: Revised the paper and approved the final version to be communicated to the esteemed journal.

All authors provided critical feedback and helped shape the research, analysis and manuscript

Availability of Data and Material

No data available to deposit as private. There are no rights

Compliance With Ethical Standards

Yes this article compliance with ethical standards of journal Consent to participate Yes. All permission granted

Consent For Publication

Yes. All permission granted

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