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MECHANICAL BEHAVIOR OF ADDITIVELY MANUFACTURED ALUMINUM METAL MATRIX COMPOSITES: A REVIEW

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ABSTRACT

Metallic alloy additive manufacturing (AM) for structural applications has attracted a lot of attention over the past 20 years as it brings a revolutionary approach to design and manufacturing. Manufacture of intricate shapes are not suitable for conventional manufacturing, and the possibility of weight reduction of components without performance degradation, is especially attractive for automotive and aerospace industries applications. This has built up a quick advancement with Titanium and Nickel based alloys in AM. On the other hand, AM with Aluminum alloys has developed slowly, nevertheless the fact that they are widely used in industry due to their superior high ratio and low density of strength to weight. Laser powder bed fusion (L-PBF) is among the widely used metal additive manufacturing (AM) techniques. It uses laser beam and a CAD model to melt powder particles at pre-defined locations. For a range of industrial applications, various alloys like nickel, copper, titanium, steel, aluminum, etc., have already been produced utilizing L-PBF.

The study reviews the performance and mechanical behavior of metal matrix composites (AMMCs) made of aluminum and created using AM processes.

Keywords: Additive Manufacturing (AM), Laser Powder Bed Fusion (L-PBF), Aluminium based metal matrix composites (AMMCs).

1. INTRODUCTION

AM of metal is the most innovative and quickly evolving processes in advanced manufacturing. [2] It is gaining a lot of interest in the metal working industry since it overcomes many restrictions that were previously thought to be part of large-scale production such as creation of intricate geometries, readily adaptable structures, notable weight reductions without sacrificing structural integrity or strength.[3]

Another amazing benefit of AM is a much shorter lead time for manufacturing. This means that new designs and components will reach the market faster, meeting customer demand sooner, and using far less material waste in the process.[4]

AM has integrated a numerous manufacturing technique (powder bed fusion, binder jetting, directed energy deposition, curing, material extrusion, lamination etc.), to develop a wide range of technologies that might be useful in the industry [2].

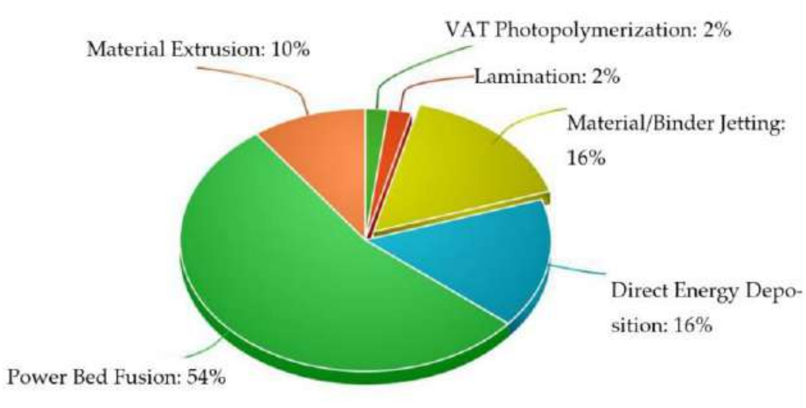

Figure 1. Metal Additive Manufacturing Market in 2020.

Aluminum alloy composites are lightweight, durable materials that find extensive application across numerous industries. This has inspired many researchers to investigate the producibility of aluminum alloy composites using AM and sparked interest in the material. In contrast to materials such as titanium and composites, Al is among the most sought-after materials for use in automobile and aerospace applications, due to the advantages, in addition to its cost-effectiveness and manufacturing capacity. The opportunities and difficulties of this manufacturing pathway are reflected in latest research published on AM with AMMC. [5]

Cast Aluminium Designation		Wrought Aluminium Designation		Applications
1xx.x	Al (99% minimum or greater)	1xxx	Al (99% minimum or greater) – H	Electrical and chemical industries
2xx.x	Al-Cu (4–4.6%)	2xxx	Al-Cu (2.2–6.8%) – T	High-strength applications, e.g. aircraft
3xx.x	Al-Si (5–17%) with Cu or Mg	3xxx	Al-Mn (0.3–1.5%) – H	Architectural and general-purpose applications
4xx.x	Al-Si (5–12%)	4xxx	Al-Si (3.6–13.5%)-Cu (0.1–4.7%)- Mg (0.05–1.3%) – H/T	Welding and brazing consumables
5xx.x	Al-Mg (5–12%)	5xxx	Al-Mg (0.5–5.5%) – H	Rolled products: automotive trim, boat hulls, architectural components
6xx.x	Unused series	6xxx	Al-Mg (0.35–1.5%)-Si (0.2–1.8%) – T	Structural applications e.g. body-in-white
7xx.x	Al-Zn (6.2–7.5%)	7xxx	Al-Zn (0.8–8.2%)-Mg (0.1–3.4%)-Cu (0.05–2.6%) – T	High-strength application, i.e. aircraft structures
8xx.x	Al-Sn	8xxx	Al with other elements like Li, Fe – H/T	
9xx.x	Al with Other elements	9xxx	Unused series	

Table 1. Designation of cast and wrought alloy [6]

L-PBF Process

L-PBF technology has become a front-runner for the production of mission-critical components. As a result, it has been widely used in recent years by many different manufacturing industries.

There are many types of L-PBF processes i.e., Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Laser Metal Fusion (LMF), Direct metal Laser Sintering (DMLS) etc from which SLM is the most popular process of manufacturing.

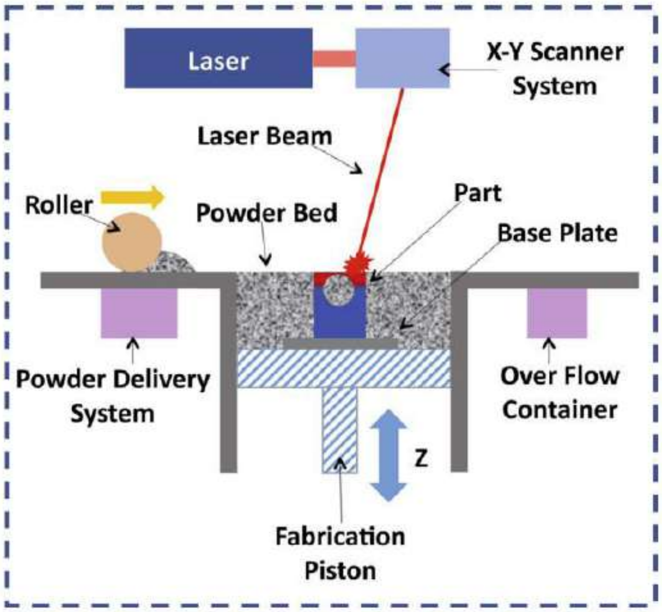

Figure 2. L-PBF Process Schematic [8]

L-PBF is a metal 3D printing process that uses a laser to generate heat, to selectively melt and fuse the metal powder particles together. Heat source scans cross-section of the part layer by layer, creating a solid metal object. L-PBF can produce high-quality, high-strength, and high-density parts with fine details and complex geometries.

2. LITERATURE SURVEY

Inadequate energy input results in insufficient melting of the powder and inadequate filling of the gaps and voids, which causes irregular voids or hot shots. Al alloys having high strength contains volatile elements (e.g., Zn, Mg, Li), which may evaporate during L-PBF and changes the microstructure of product. It is observed that, in some cases, alteration in the composition because of evaporation of some alloying elements even increase susceptibility to cracking. [5] It effects on mechanical properties of materials like yield strength, ultimate tensile strength, etc. The samples manufactured with L-PBF cools at a very quick rate as compared to conventional casting. To reduce defects like cracking, hot tears, hot shots, irregular voids etc the reinforcement materials like B4C, Sic, Alumina Al2O3 etc are added in % wt.

Following table shows the literature survey of the research work conducted by researchers on Al materials by L-PBF.

Sr. No	Author	Material	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	Fracture Strain	Elongation (%)
1	**Nesma T. Aboulkhair et al. [7]**	SLM AlSi10Mg. As Fabricated	268 ± 2	333±15	--	--
		SLM AlSi10Mg Heat treated T6	239 ± 2	73± 4	--	--
2	**K.G. Prashanth et al. [9]**	SLM Al-12Si As fabricated	260	--	3%	--
		SLM Al-12Si Heat Treated (Annealing at	95	--	15%	--

		723K)				
3	**J. Hunter et al. [10]**	SLM Al 7075+ Zr T6	527.5±5.5	587±6	--	8.4 ± 0.8
		SLM Al 7075	325-373	383-417		3.8 ± 5.4
4	**Qingbo Jia et al. [12]**	Al-Mn-Sc as fabricated	431.0 ± 12.7	--	--	21.5 ± 2.0
		Al-Mn-Sc heat treated (ageing)	570.9 ± 4.3	--	--	18.1 ± 3.1

Table 1. Survey of mechanical properties

1. Nesma T. Aboulkhair et al. [7] in their research paper investigated the various mechanical properties of SLM AlSi10Mg. Two different kinds of samples, one without heat treatment and the other with heat treatment (T6) have been collected for testing. Here reinforcement materials are not added to the samples. In this research they observed that when heat treatment is applied, the microstructure of the material resulted in softening rather than hardening. The mechanical properties are decreased.

2. K.G. Prashanth et al. [9] in their research investigated the various mechanical properties of Al-12Si produced by SLM. Two different kinds of samples, one without heat treatment and the other with heat treatment i.e., annealing have been collected for testing. They observed that the mechanical properties are reduced after heat treatment process. They also observed that yield strength of sample produced by SLM is higher than conventional process.

3. J Hunter et al. [10] conducted tests on gas atomized additively manufactured Al 7075 without reinforcement and Al 7075 by reinforcement with zirconium. Here it is observed that mechanical properties like yield strength, ultimate tensile strength, elongation are improved when the reinforcement materials are added in the specimen.

4. Qingbo Jia et al. [12] conducted mechanical tests on the specimen of Al-Mn-Sc alloy as fabricated and after ageing heat. The Al is reinforced with Mn & Sc particles. They found that if Al is reinforced with composites, there is improvement in mechanical behavior of material even after heat treatment process.

5. Montero Sistiaga et al. [11] conducted compressive stress, strain tests on the Al 7075+4% SiC SLM samples. Three samples were considered a) as built (AB4) b) Al 7075+ 4% SiC T6.

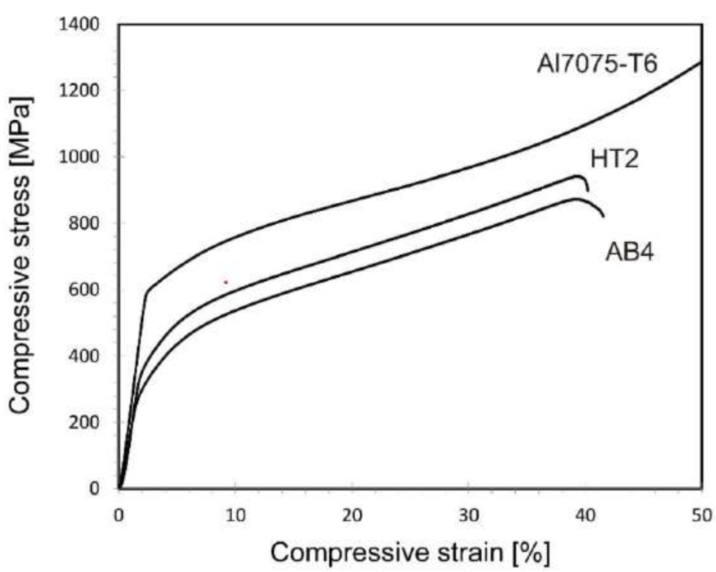

Figure 3: Stress-strain curves for SLM samples in as built (AB4) and heat-treated HT2 and compared to conventional Al 7075 T6.[11]

The authors observed after reinforcement of AMMC Al7075 compressive strength is improved as compared to as built and heat-treated materials.

3. CONCLUSION

The percentage of Al in the series (1xxx, 2xxx, 3xxx, 4xxx) is greater than 95%, while the series (5xxx, 6xxx, 7xxx) has a higher percentage ie 10-12 % of other alloy elements (Si, Mg, Mn, Zn etc.). Consequently, it leads to an improvement in mechanical properties such as strength, hardness, tensile stress etc.

The quantity of study on high-strength Al-alloys is still low due to the problem of hot cracking brought on by alloy solidification at high cooling rates, are experienced in AM processing.

If Al specimen is fabricated without reinforcement, there is formation of cracks, holes etc in the specimen because of rapid cooling. As a result, mechanical qualities decline.

Additionally, heat causes some of the components in Al alloys to disappear after heat treatment. But if Al is reinforced with composite materials like B4C, SiC,Al_2O_3 etc. its strength gets increased. Therefore even if elements disappears, the composite materials acquires its space. As a result, there are less pores and cracks formed, which improves the mechanical qualities.

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