Comparison Studies On Tensile Behavior of Al Mg_{10} Si Alloy Produced by DMLS & A360 Alloy By Die Casting Method

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Abstract: This study has been undertaken to investigate the tensile behavior of Al Mg_{10} Si alloy produced by direct metal laser sintering process and A360 alloy by die casting method. The next industry revolution is widely predicted to be additive manufacturing, with an evolution of autonomous and electric vehicles, the need for light weight material will be the primary focus without compromising on the performance. One such potential technology can be addressed by metal additive manufacturing which is commonly known as metal 3D Printing. Additive manufacturing gives more space to complex design and scope intuitive as it poses fewer manufacturing constraints when compared to traditional casting techniques. As we know that aluminum alloys are one of the primary materials used for producing such lightweight components and direct metal laser sintering (DMLS) has one such potential manufacturing technology. In this study, one set of specimens were 3D printed by DMLS technique and other set of specimens were produced by using die casting technique for evaluating the tensile properties. Superior mechanical behavior and better strength to weight ratio were observed for the 3D printed samples.

Index Terms **– Additive manufacturing, DMLS, Al Mg_{10} Si alloy, Tensile Properties, A360 alloy and Die casting.**

I. Introduction

Recent advancement in additive manufacturing of metallic materials has attracted substantial attention from industry [1]. Additive Manufacturing is emerging as a main technology for prototyping small batch productions of structural and functional components. The tool-free fabrication of additive manufacturing has enabled on-demand production and high potential to revolutionize conventional production processes [2] & [3]. Considering the difficulties associated with casting, forming, and machining of Al Mg_{10} Si, powder metallurgy and additive manufacturing techniques can be selected for batch production of Al Mg_{10} Si [4]. The components produced by powder metallurgy results in porous structures and brings the possibility of direct metal laser sintering (DMLS) of aluminum upon focus. Additive manufacturing (AM) technique involves production of high strength complex shape parts at low cost and, it is possible to produce combination of metal and non-metal compositions.

Direct metal laser sintering (DMLS) is one of the additive manufacturing techniques from which we can produce near net shaped, homogeneous and less scrap materials [4]. It also requires very less or no finishing operations to fabricate the final product. DMLS parts can be manufactured with controlled porosity. Therefore, this method is proved to be one of the best solid-state powder processing methods to prepare alloy of elemental powder. Many synthesis routes like powder metallurgy, equal channel angular processing, hydrostatic extrusion, high pressure torsion, ultrasonic shot peening, hydraulic pressings are used to refine the structure of metals and alloys by plastic deformation and solid solution mechanism. But DMLS is one of the simplest and newly developed method to achieve extreme refinement and quality components [11].

The mechanical and microstructure of the Al alloy processed by DMLS depends on the chemical composition of the alloy mainly %wt. of Si and Mg [5]. The Si addition in Al alloys plays a vital role in microstructural evolution and helps in improving hot cracks. The Mg content in the alloy helps to improve the strength by promoting age hardening i.e., which is having very high coefficient of thermal expansion results in solidification and liquification cracking [6]. However, Al Mg_{10} Si alloy processed by DMLS possess excellent fluidity and low shrinkage mainly because, its composition is very close to eutectic point [7]. Baxter compared the casting to 3D printed mechanical behavior, concluding superior mechanical behavior for 3D printing, however, the study was not done for the different build orientation for 3D printing. In this study attempt will be made to evaluate the strain hardening behavior of Al Mg_{10} Si and A360 [8]. Comparative study will be done for two different built orientation of 3D printed specimens and casted A360. The main objective of this study is to understand the anisotropy behavior of 3D printed specimens and to study the effect of [10] strain hardening behavior on two different build orientation and to compare the results with conventionally [9] die casted A360 Al alloy.

II. Experimental details.

The material used in this study is die casted A360 and 3D printed Al Mg_{10} Si alloy from DMLS. The chemical composition of material was tested using optical spectrometer. The powders used for DMLS had an average size of 20 mm. Three samples of 3D printed, and three samples of casted alloy were used for tensile testing. Extreme precaution was taken to use only fresh powders to produce the 3D printed samples. Process parameters play major role in influencing the mechanical behavior. Out of many process parameters, there are few major parameters which influence the mechanical behavior, those are scanning speed, hatch distance, laser power, laser beam diameter. In this study Power 370 kW, Hatch spacing 0.19 mm, scanning speed 1300 mm/s and 0.03 mm layer thickness are used. The tensile test was performed according to ASTM E8M standard figure 2. The figure 1 shows printing direction and is recommended for DMLS as per ISO 6829, DIN 50,125 and DIN EN 10002-1. In this study, cylindrical samples are made because they are easy to handle in machine and exhibit homogenous stress distribution throughout the sample. Both end of the samples is M10 threaded for gripping purpose. The material composition is shown in below Table 1.

3D printed build orientation is shown in below figure 1.

Dog bone coupon dimensions are shown in below figure 2.

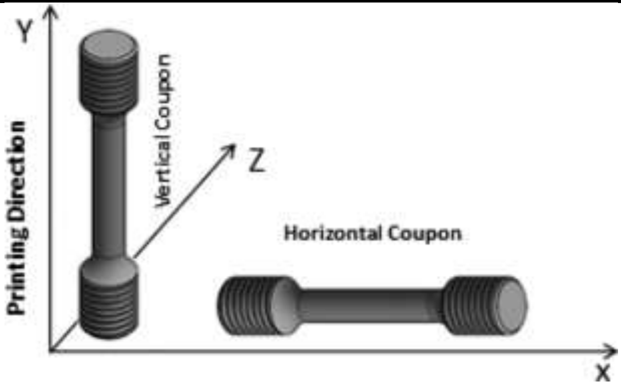

Figure 1: 3D printing orientation.

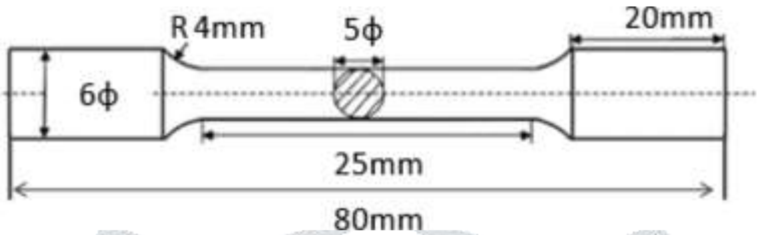

Figure 2: Specimen dimension.

MATERIAL	COPPER	IRON	MAGNESIUM	MANGANESE	NICKEL	SILICON	TIN	ZINC
A360	0.60	1.3	10	0.35	0.50	0.60	0.15	0.50
Al Mg_{10} Si	0.05	0.55	10	0.45	0.05	0.45	0.05	0.1

Table 1: Material composition in % of wt.

III. Results and discussion.

3.1 Tensile Properties.

The figure 3 shows the stress strain curve for 3D - printed specimens and die casted A360 Al alloy. The 3D printed specimens were more brittle when compared to A360 cast alloy. However, when compared with horizontally and vertically built specimens, the horizontally built specimens showed higher strength. The less strength of vertically built specimens could be due to the presence of pores, voids, and laser spatter. There was no significant necking observed in all is the specimens because of the process induced brittleness. This was proven by the stress strain curves where we can observe fracture stress equal to ultimate tensile strength. The tensile strength of DMLS Al Mg_{10} Si is higher when compared to A360 die casted alloy, which is more comparable alloy with respect to Al Mg_{10} Si alloy. However, from the tensile results it very clear that both yield strength and ductility is almost 8% more yield and 35% more ductile than the A360 die cast alloy, from literature it is also known that the ductility of the 3- D printed Al Mg_{10} Si can be increased even further by heat treating it, to relieve the residual stress. This makes the 3D- printed alloy more suitable for applications that require light weight, high strength, and good ductility capabilities as a design consideration.

The T6-like treatment can be chosen for improving ductility by compromising the strength in figure we see the variation of yield strength UTS and ductility of horizontally and vertically 3- D printed coupon along with A360 die casted alloy tensile. To study the effect of isotropy effect on the tensile properties of 3-D printed part. We printed the specimens with 2 different orientation i.e., horizontally, and vertical direction. However, we can see minimum difference in tensile properties of both horizontally and vertically built specimens. Here vertically built specimens had lesser strength when compared to horizontally built specimens because in vertically built coups, the crack will propagate between the layers or in the plane of several layers as shown in figure 4. The horizontally built specimens require higher load because the crack should propagate against the layer i.e., the layer offers some amount of resistance against load which is evident from our results shown in figure 5.

The table 2 presents comparative tensile test results of 3D printed and casted specimens. The differences in the mechanical behavior of 3D printed horizontal and vertical specimens seen in the stress strain curves Baxter in his study, the results of horizontal specimens are said to be 240 MPa yield strength, 386 UTS and 8.8% failure strain. In this study the recorded values for horizontal specimens 241 MPa yield, 408 MPa UTS and 10.5% failure strain. There is a clear difference in the two studies, The UTS and % failure strain are clearly more, this is due to the selection of process parameters. This clearly shows the change in mechanical behavior of same material produced by different process parameters.

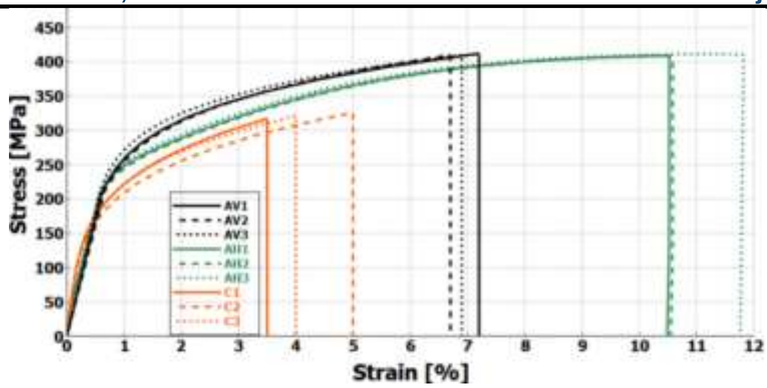

Figure 3: Stress Strain Curves.

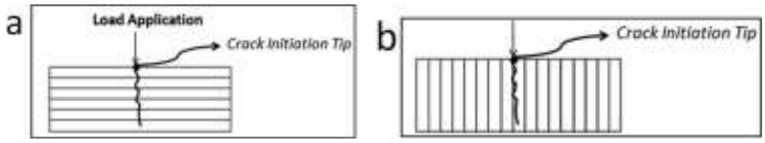

Figure 4: (a) Crack propagation in horizontal; (b) Crack propagation in vertical.

Specimen	Yield Stress [MPa]	Ultimate Tensile Stress [MPa]	% of Elongation
AH1	240.3	408	10.5
AH2	241.7	408	10.5
AH3	243.8	411	11.7
AV1	225	412	7
AV2	223	410	6.5
AV3	225	408	6.7
C1	165	317	3.5
C2	155	326	5
C3	168	321	4

Table 2: Test result comparison Al Mg_{10} Si Vs A360.

3.2 Strain hardening behavior.

Strain hardening is an important phenomenon to understand the material strengthening. The strain hardening exponent gives more insights on the plastic behavior of the material post yielding due to work done on the specimens. The obtained stress strain curves from tensile test are used to study the strain hardening behavior. For this study assuming the flow curves can be represented by Holloman relationship.

$$\sigma = K * \varepsilon^n$$

Were,

σ= True Stress.

ε= True Strain.

K= Strength Coefficient.

As per equation, plotting natural log of true stress vs natural log true strain should result in straight line and taking slope of the same will give n strain hardening exponent. Corresponding true stress strain data is considered for 3D printed and casted for demining the curves as shown in above Figure 5. Each of the curve follow the straight-line equation, thereby validating equation. The strain hardening was calculated for each of the specimens by taking the slope. Figure 5 also shows the value of n for 3D printed and casted. It is also known that the material in necking resistance increases with increasing ductility with higher n value, therefore higher the n value lesser will be the accumulation of residual stress which results in lesser work hardening. Usually, most metals and alloys have the n value between 0 and 1. Strain hardening exponent shows different values for all the specimens. There is significant difference in the hardening between the 3D printed horizontal and vertical specimens. The strain hardening exponent for casted and additively manufactured vertical and horizontal specimens are 0.16, 0.17 and 0.22, respectively. The casted A360 has the minimum hardening exponent followed by vertical 3D printed and horizontal 3D printed specimens suggesting casted A306 is more brittle than the 3D printed parts. The hardening exponent of the vertical specimens is 22% less than the horizontal specimens, more brittle resulting in lesser strain to failure. Although same process parameters are used to produce the specimens, there is more layer stack up in the vertical build resulting in more accumulation of residual stress during build, due to which more work done on the specimens in turn more brittle behavior than horizontal build.

Casted A360 is more brittle than the DMLS as suggested by the strain hardening exponent and failure strain of 4% which is lesser than the DMLS having 10.5% and 6.7% strain to failure for horizontal and vertical specimens. The difference in young's modulus is marginal, however yield strength, tensile strength, and hardness of DMLS is far more superior to its counterpart casted A360. This comparison clearly highlights the superior mechanical behavior of 3D printed Al Mg_{10} Si overcast A360 and echoing the existence of anisotropy behavior for different build orientation.

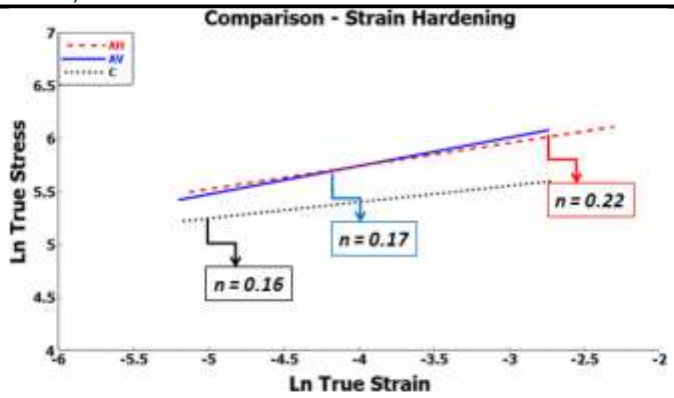

Figure 5: Strain hardening.

IV. CONCLUSION.

In conclusion, investigated three specimens of 3D printed Al Mg_{10} Si alloy produced by direct metal laser sintering (DLMS) with respect to three specimens of A360 produced by die casting method for its tensile strength and strain hardening. Die cast A360 alloys are tested, and mechanical behavior is compared with DLMS manufactured Al Mg_{10} Si specimens. We can conclude that the tensile strength of 3D printed specimens increases in 21.43% and yield strength increase in 32.76% when compared to specimens of A360 alloy.

The tensile strength, yield strength and % of failure strain is significantly higher than its counterpart A360 die cast alloy. The 3D printed specimens exhibit extremely consistent results as there are no major differences in the stress strain curves, indicating highly repeatable mechanical behavior in 3D printing component. To achieve consistent mechanical property, care should be taken in material handling and storage.

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