ALUMINUM-BASED COMPOSITION, ALUMINUM ALLOY POWDER, ALUMINUM ALLOY ADDITIVE MANUFACTURED PRODUCT, METHOD OF FORMING ALUMINUM ALLOY POWDER, AND METHOD OF ADDITIVE MANUFACTURED PRODUCT

Technical Field

[0001] The invention relates to the formulation of the powder chemical composition and processing conditions of the powder gas atomization, to achieve crack-free moderate and high strength aluminum alloy powders and parts.

[0002] The invention further relates to the microstructure and property control for the moderate strength aluminum alloy Al6xxx powder developed for additive manufacturing.

Related Art

[0003] Moderate and high-strength aluminum alloys play a significant role in the aerospace, automotive and semiconductor industries. These alloys include the Al–Cu (2xxx), Al–Mg–Si (6xxx), and Al–Zn (7xxx) alloys. Laser powder bed fusion (LPBF) processing of these aluminum alloys remains challenging due to the formation of cracks. To address the solidification cracking issue, two different methods are mainly adopted: (1) optimizing the processing parameters; (2) modifying the powder's chemical composition.

[0004] (1) Optimizing printing process parameters:

[0005] The cracks found in the LPBF high strength aluminum alloys are mainly due to hot cracking, which is located at the grain boundaries. To eliminate the solidification cracks, a type of hot cracking commonly found in additively manufactured moderate- and high-strength aluminum alloys, adjusting the process parameters is usually first adopted. By adjusting the LPBF processing parameters, the cooling rate, the temperature thermal gradient, and the solidification rate are supposed to be tailored, which aims to decrease the stress between the inter-dendrite regions or increase the liquid backfilling ability in the mushy zone, hence enhancing the crack resistance.

[0006] The scanning speed is the most common LPBF processing parameter to be optimized. The correlation between the scanning speed and the crack susceptibility is extensively studied.

The results from the literature have showed that the crack susceptibility increases with the scanning speed. Thus, decreasing the scanning speed is one of the common methods to eliminate the cracks during the LPBF process. This method has been successfully adopted in Al2xxx alloys, such as Al-Cu-Mg and Al2195. However, this method is not successful when it comes to Al6xxx and Al7xxx alloys.

[0007] Apart from the scanning speed, increasing the preheating temperature is another approach to resolve the cracking issue. Increasing the preheating temperature will decrease the cooling rate during the solidification process, which will prevent cracking. A 500°C preheating temperature has been proven to successfully resolve the cracking issue in Al6061 alloys due to the reduced solidification undercooling. However, for the case of Al7075 alloy, it has been reported that preheating the baseplate during printing could not eliminate the cracking. On the contrary, it could introduce more serious cracks in the samples. Although preheating at 500°C can effectively address the crack issue in Al6061 alloy, it should be noted that this temperature requirement poses significant challenges due to the limited capabilities of most commercial LPBF machines. Thus, this will inhibit the implementation of the approach.

[0008] Besides, the hatch spacing and the defocusing distance have also proven to be contributing factors to the crack formation in the Al-Cu alloys. The effect of the defocusing distance on the crack formation in Al7050 has also been studied but the crack issue has not been resolved. Hence, optimizing the processing parameters to eliminate the cracks during LPBF processing is more effective in Al-Cu alloys than in the case of Al-Mg-Si and Al-Zn alloys.

[0009] (2) Modifying Al powder's chemical composition:

[0010] The concept of modifying the powder's chemical composition to eliminate the cracking issue is to introduce secondary particles so as to refine the grains. By introducing elements like Sc and Zr, nucleation sites can be formed before the solidification of α-Al. The grain refinement could prevent crack formation/propagation and enhance the grain boundary strengthening. Compared with coarse columnar grains, fine equiaxed grains are beneficial for eliminating cracks due to the following reasons: (1) the fine equiaxed grains made the crack propagation more torturous as compared with the columnar grains; (2) the fine equiaxed grains could increase the critical stress for hot-cracking and delay the onset of coherence of dendrites. The grain refinement efficiency for the introduced inoculants depends on the lattice mismatch.

[0011] This method has been reported in a wide range of aluminum alloys for LPBF, such as Al-Cu-Mg, Al-Mn-Mg, and Al-Zn. The commercially available powder utilizing this method is Scalmalloy®, where there is presence of Sc and Zr in a moderate strength Al-Mg alloys. The

derivative for Scalmalloy® has also been studied, such as Addalloy™(Al-Mg-Zr). As for the Al7xxx alloys, 7A77.60L alloy (Al-Zn-Mg-Cu-Zr), is also commercially available. The yield strength (YS) and the ultimate tensile strength (UTS) can be 490-585 MPa and 520-615 MPa, while the elongation is 6-14%.

[0012] Regarding the derivatives of two most popular moderate and high strength aluminum alloys: Al6061 and Al7075, the information in the literature is very limited. It has been reported an AlZnMgScZr alloy fabricated by LPBF which achieved the YS and UTS of 418.3 and 425.7 MPa, respectively after T6 heat treatment. It has been reported an AlZnMgCuScZr alloy fabricated by LPBF with the YS of 647 MPa. Airbus has also filed an IP in EU, which covers a very broad chemical composition range.

[0013] Apart from the above information, the ceramic has also been introduced in Al6061 and Al7050 alloys for LPBF process by Elementum 3D. Both alloys contain 2% ceramic. For Al6061 with 2% ceramic, the YS and UTS can be 297±14 MPa and 331±20 MPa respectively and the elongation is 12±1.5% after T6 treatment. For Al7050 with 2% ceramic, the YS and UTS can be 469±3 MPa and 504±3 MPa respectively and the elongation is 6±1.5% after HIP and T74 treatment. However, the details of the ceramic have not been reported.

[0014] Furthermore, in order to achieve crack-free and optimal strength of the LPBF Al6061 and Al7075 parts, the quality of the powders is critical. However, there is no literature record on the correlation between the gas atomization (GA) processing of the powders and the resultant powder's quality (in terms of chemical composition of the powders, powder morphology, powder size distribution and GA powder yield).

SUMMARY OF INVENTION

[0015] To achieve crack-free moderate and high strength aluminum alloy powders and additive manufactured products manufactured using such alloy powders, in some embodiments, the present disclosure includes the following items:

[0016] Item 1: an aluminum-based composition, which includes: aluminum, magnesium, copper, chromium, silicon, scandium, and zirconium; and one or more other metals which are not aluminum, magnesium, copper, chromium, scandium, and zirconium, wherein based on a total amount of the aluminum-based composition, the scandium is present in an amount of 0.46 mass% to 0.80 mass% and the zirconium is present in an amount of 0.15 mass% to 0.40 mass%.

[0017] Item 2: the composition according to item 1, wherein based on the total amount of the

aluminum-based composition, the scandium is present in an amount of 0.46 mass% to 0.72 mass% and the zirconium is present in an amount of 0.15 mass% to 0.36 mass%.

[0018] Item 3: the composition according to item 1, wherein based on the total amount of the aluminum-based composition, the magnesium is present in an amount of 0.8 mass% to 1.4 mass%.

[0019] Item 4: the composition according to item 3, wherein based on the total amount of the aluminum-based composition, the magnesium is present in an amount of 0.8 mass% to 1.2 mass%.

[0020] Item 5: the composition according to item 1, wherein based on the total amount of the aluminum-based composition, the copper is present in an amount of 0.15 mass% to 0.4 mass%.

[0021] Item 6: the composition according to item 1, wherein based on the total amount of the aluminum-based composition, the chromium is present in an amount of 0.04 mass% to 0.45 mass%.

[0022] Item 7: the composition according to item 6, wherein based on the total amount of the aluminum-based composition, the chromium is present in an amount of 0.04 mass% to 0.35 mass%.

[0023] Item 8: the composition according to item 1, wherein based on the total amount of the aluminum-based composition, the silicon is present in an amount of 0.4 mass% to 1.0 mass%.

[0024] Item 9: the composition according to item 8, wherein based on the total amount of the aluminum-based composition, the silicon is present in an amount of 0.4 mass% to 0.8 mass%.

[0025] Item 10: the composition according to item 1, further comprising zinc present in an amount of less than 0.25 mass%, based on the total amount of the aluminum-based composition.

[0026] Item 11: the composition according to item 1, wherein the one or more other metals comprise iron, manganese, and/or titanium.

[0027] Item 12: the composition according to item 11, wherein based on the total amount of the aluminum-based composition, the iron is present in an amount of less than 0.2 mass%, and the manganese and the titanium are each present in an amount of less than 0.3 mass%.

[0028] Item 13: the composition according to item 12, wherein based on the total amount of the aluminum-based composition, the iron is present in an amount of less than 0.2 mass%, and the manganese and the titanium are each present in an amount of less than 0.15 mass%.

[0029] Item 14: an aluminum-based composition, including aluminum, zinc, magnesium, copper, chromium, scandium, and zirconium; and one or more other metals which are not aluminum, zinc, magnesium, copper, chromium, scandium, and zirconium, wherein based on a total amount of the aluminum-based composition, the scandium is present in an amount of 0.35 mass% to 1.04 mass% and the zirconium is present in an amount of 0.15 mass% to 0.52 mass%.

[0030] Item 15: the composition according to item 14, wherein based on the total amount of the aluminum-based composition, the zinc is present in an amount of 5.5 mass% to 7.0 mass%.

[0031] Item 16: the composition according to item 14, wherein based on the total amount of the aluminum-based composition, the magnesium is present in an amount of 2.3 mass% to 3.2 mass%.

[0032] Item 17: the composition according to item 14, wherein based on the total amount of the aluminum-based composition, the copper is present in an amount of 1.2 mass% to 2.0 mass%.

[0033] Item 18: the composition according to item 14, wherein based on the total amount of the aluminum-based composition, the chromium is present in an amount of 0.28 mass% or less.

[0034] Item 19: the composition according to item 14, further comprising silicon present in an amount of less than 0.2 mass%, based on the total amount of the aluminum-based composition.

[0035] Item 20: the composition according to item 14, wherein the one or more other metals comprise iron, manganese, titanium, nickel, lead, tin, and/or vanadium.

[0036] Item 21: the composition according to item 15, wherein based on the total amount of the aluminum-based composition, the iron is present in an amount of less than 0.2 mass%, the manganese and the titanium are each present in an amount of 0.1 mass% or less, the nickel and the lead are each present in an amount of 0.01 mass% or less, and the tin and the vanadium are each present in an amount of less than 0.01 mass%.

[0037] Item 22: the composition according to item 15, further comprising: oxygen present in an amount of less than 0.03 mass%, nitrogen present in an amount of less than 0.01 mass%, and hydrogen present in an amount of 0.001 mass%, based on the total amount of the aluminum-based composition.

[0038] The above elements shown in Items 1 to Items 22 can be appropriately combined without the inclusion of contradicting features. For example, an embodiment including all of Items 1-3, 5-6, 8, 10-12 is exemplified; an embodiment including all of Items 1-2, 4, 5, 7, 9-11, 13 is exemplified, and an embodiment including all of Items 14-22 is exemplified. Other combinations are possible, which may be adjusted by those having ordinary skill in the art.

[0039] Item 23:An aluminum-based composition consisting of: magnesium, copper, chromium, silicon, scandium, and zirconium; one or more other metals which are not aluminum, magnesium, copper, chromium, scandium, and zirconium; and the balance aluminum and inevitable impurities, wherein based on a total amount of the aluminum-based composition , the scandium is present in an amount of 0.46 mass% to 0.80 mass% and the zirconium is present in an amount of 0.15 mass% to 0.40 mass%. The one or more other metals is selected from the group consisting of iron manganese, and/or titanium.

[0040] Item 24: the composition according to any one of item 1 to 23, wherein the composition is an aluminum alloy powder.

[0041] Item 25: the composition according to any one of item 1 to 23, wherein the composition is an aluminum alloy additive manufactured product.

[0042] Item 26: a method of forming an aluminum alloy powder, the method comprising: induction-melting the aluminum-based composition according to item 1 to produce a molten aluminum alloy; and subjecting the molten aluminum alloy to gas atomization.

[0043] Item 27: the method according to item 26, wherein the gas atomization is carried out at: (i) a pressure of 40 to 45 bar; (ii) a power of 20 to 30 kW; and/or (iii) a temperature of 60°C to 100°C.

[0044] Item 28: the method according to item 26, wherein the aluminum alloy powder is absent of any crack.

[0045] Item 29: a method of forming an aluminum alloy powder, the method comprising: induction-melting the aluminum-based composition according to item 14 to produce a molten aluminum alloy; and subjecting the molten aluminum alloy to gas atomization.

[0046] Item 30: the method according to item 29, wherein the gas atomization is carried out at: (i) a pressure of 40 to 45 bar; (ii) a power of 20 to 30 kW; and/or (iii) a temperature of 60°C to 100°C.

[0047] Item 31: the method according to item 29, wherein the aluminum alloy powder is absent of any crack.

[0048] Item 32: a method of additive manufacturing a product, comprising: forming an additive manufactured product using the aluminum alloy powder of item 24 as a raw material powder for additive manufacturing.

[0049] Item 33: the method according to item 32, wherein the additive manufacturing is a powder bed fusion method using an electron beam or laser, or a directed energy deposition method using an electron beam or laser.

[0050] By using the aluminum-based composition above for forming an aluminum alloy powder and forming additive manufactured products (or laminated molded products or bulk), the obtained product will be crack-free, and the yield strength, ultimate tensile strength and elongation are all in a desired range.

BRIEF DESCRIPTION OF DRAWINGS

[0051] FIG. 1 illustrates the relationship between the mole fraction of the solid and the temperature of Al5.5Zn2.3Mg1.2Cu and Al5.5Zn2.3Mg1.2Cu0.28Cr.

[0052] FIG. 2 illustrates the calculation results for the effect of Sc on the critical cooling rate for Al7xxx: Orange dash line – Critical cooling rate = 1×10^6 K/s.

[0053] FIG. 3 illustrates the calculation results for the effect of Sc on the critical cooling rate for Al6xxx: Orange dash line – Critical cooling rate = 5×10^5 K/s.

[0054] FIG. 4 illustrates the particle size distribution for Al6xxx with different Sc and Zr contents during GA process.

[0055] FIG. 5 illustrates the particle size distribution for Al7xxx with different Sc and Zr contents during GA process.

[0056] FIG. 6 illustrates the yield (%) of the gas atomization process for atomized Al6xxx using: (a) different gas pressure; (b) different heating power.

[0057] FIG. 7 illustrates the powder size (μm) of the Al6xxx powder, atomized using: (a) different gas pressure; (b) different heating power.

[0058] FIG. 8 illustrates atomized Al6xxx powder size distribution using the heating power of: (a) 25 kW; (b) 22 kW; (c) 20 kW.

[0059] FIG. 9 illustrates a graph showing the effect of heating power on the powder morphology of the atomized Al6xxx powders.

[0060] FIG. 10 illustrates a representative scanning electron microscopy (SEM) image of the atomized Al6xxx powders.

[0061] FIG. 11 illustrates the (a) yield (%) and (b) powder size (μm) of the Al7xxx atomized powders using different heating power.

[0062] FIG. 12 illustrates atomized Al7xxx powder size distribution using the heating power of: (a) 22 kW; (b) 25 kW; (c) 28 kW.

[0063] FIG. 13 illustrates a graph showing the effect of heating power on the powder morphology of the atomized Al7xxx powders.

[0064] FIG. 14 illustrates a representative SEM image of the atomized Al7xxx powders.

[0065] FIG. 15 illustrates EBSD results showing the insufficient ultrafine grains in the sample printed using the GA powder which is lack of Zr.

[0066] FIG. 16 illustrates a schematic configuration of a laser additive manufacturing method.

[0067] FIG. 17 is a microscopy image of the additively manufactured product B1.

[0068] FIG. 18 is a microscopy image of the additively manufactured product B2.

[0069] FIG. 19 is a microscopy image of the additively manufactured product B3.

[0070] FIG. 20 is a microscopy image of the additively manufactured product B4.

[0071] FIG. 21 is a microscopy image of the additively manufactured product B5.

[0072] FIG. 22 illustrates the microstructure of the sample of Example E1.

[0073] FIG. 23 illustrates the microstructure of the sample of Example E2.

[0074] FIG. 24 illustrates the TEM results of the DA sample of Example E3.

[0075] FIG. 25 illustrates the TEM results of the STA sample of Example E4.

DESCRIPTION OF EMBODIMENTS

[0076] In the present disclosure, the expression "mass%" denotes for weight percentage, or in brevity weight percent. The mass% recited in one or more of the examples of the present disclosure are based on a total amount (100%) of the aluminum-based composition.

[0077] In some embodiments, the present disclosure includes the following items (1)~(3):

[0078] (1) the chemical composition for two types of aluminum alloys: Al6xxx (moderate strength / wt.%: Zn<0.25, Mg 0.8-1.4, Si 0.4-1.0, Cu 0.15-0.4, Cr 0.04-0.45, Sc 0.46-0.8, Zr 0.15-0.4, Fe <0.2, Mn <0.3, Ti <0.3, other total≤0.15) and Al7xxx (high strength / wt.%: Zn 5.5-7, Mg 2.3-3.2, Cu 1.2-2.0, Cr 0-0.28, Sc 0.35-1.04, Zr 0.15-0.52, Fe <0.2, Si <0.2, Mn ≤0.1, Ti ≤0.1, Ni ≤0.01, Pb ≤0.01, Sn <0.01, V <0.01, O <0.03, N <0.01, H <0.001, Other total ≤0.15) alloys;

[0079] (2) an electrode induction-melting gas atomization (EIGA) process to produce the powders suitable for additive manufacturing process: (Power: 20-25 kW, Gas Pressure: 45 bar).

[0080] (3) a laminated molded product using the aluminum alloy powder obtained by the EIGA process as a raw material powder for additive manufacturing (AM), wherein the additive manufacturing is a powder bed fusion (PBF) method using an electron beam or laser, or a directed energy deposition (DED) method using an electron beam or laser.

[0081] The above chemical compositions are modified based on the Al6061 and Al7075 alloys. To eliminate the crack in Al6xxx and Al7xxx alloys during both GA process and LPBF process, the compositions of Sc and Zr are the most important. For the lower limit of the Sc and Zr, it depends on whether $Al_3(Sc,Zr)$ can nucleate before the solidification of α-Al take place during the process. According to the time dependent nucleation theory, the nucleation incubation time can be calculated by Eq. (1):

$$\tau = \frac{7.2R[2 - 3cos\theta + cos\theta^3]}{4(1 - cos\theta)} \cdot \frac{a^4}{d_a^2 x_{L.eff}} \cdot \frac{T_r}{DS_m \Delta T_r^2} \quad (1)$$

where R is the gas constant, T_r=T/T_L, T_L is the equilibrium liquidus temperature, $\Delta T_r = 1 - T_r$; θ is the contact angle, which equals to 90°; a is the atomic jumping distance, which is 0.5 nm; S_m is the molar entropy of fusion, which is 42.2 J/m^3 for Al_3Sc and 29.3 J/m^3 for Al_3Zr; $x_{L.eff}$ is the effective alloy concentration, which equals to $x_{L,i}/x_{S,i}$, $x_{L,i}$ is the atomic concentration of element i in liquid and $x_{S,i}$ is atomic concentration of element i in the solid phase; D is the diffusion coefficient in the melt; d_a is the average atomic diameter of the solid phase which can be expressed as:

$$d_a = \left[\frac{W_m}{N_a \rho}\right]^{1/3} \quad (2)$$

$$W_m = \sum x_i W_m^i \quad (3)$$

where ρ is the density of the solid phase, N_a is the Avogadro constant, x_i is the molar fraction of element i in the solid phase, and W_m^i is the molar weight of atom i. The diffusion coefficient of the element i in the melt D can be calculated based on the Stokes-Einstein relationship:

$$\frac{\eta D}{T} = \frac{k}{6d_{a,i}} \quad (4)$$

where k is the Boltzmann's constant, $d_{a,i}$ is the average distance between the atoms which can be estimated by Eq. (2). The viscosity η of the melt is calculated from:

$$\eta = 10^{-4.3} exp\ [3.34T_L/(T - 0.33T_L) \quad (5)$$

where T_L is the liquidus temperature of the alloy. The critical cooling rate for the suppression of the $Al_3(Sc,Zr)$ $\dot{T}$ can be calculated by:

$$\dot{T} = \frac{\Delta T}{\tau} \quad (6)$$

where $\Delta T = T_n - T$, T_n is the nucleation temperature for $Al_3(Sc,Zr)$ in equilibrium solidification. Considering whether the $Al_3(Sc,Zr)$ will nucleate before the nucleation of α-Al, T is the nucleation temperature of α-Al.

[0082] The density and the temperature were calculated by the Thermo-Calc software with the TCAl8 database. Al5.5Zn2.3Mg1.2Cu and Al0.9Mg0.4Si0.2Cu were chosen as the representatives for original Al6061 and Al7075. The effect of Cr was first proven to have little effect on the crack initiation. FIG. 1 demonstrates the relationship between the mole fraction of the solid and the temperature, which indicates that the Cr has little effect on the nucleation temperature of the α-Al when increasing from 0% to 0.28%.

[0083] For a better thermal stability, the weight percentage ratio of the Sc:Zr is chosen as 2:1. The calculation results for the effect of Sc on the critical cooling rate for Al7xxx is shown in FIG. 2. With the increasing of the content of Sc, the critical cooling rate increases. In LPBF process of aluminum alloys, the cooling rate of the melt pool reaches 10^5-10^6 K/s in the edge of the melt pool boundaries for the aluminum alloys. The cooling rate become higher when it comes to the melt pool center. For Al7xxx which is very sensitive for the crack initiation, it is necessary to form a region of the equiaxed grains instead of only forming in the edge of the melt pool. Hence, the critical cooling rate is chosen as 1×10^6 K/s. The lower limit of Sc and Zr for the Al7xxx are 0.40% and 0.20%, respectively.

[0084] The calculation results for the effect of Sc on the critical cooling rate for Al6xxx is shown in FIG. 3. Al6xxx possess the less crack susceptibility when comparing with Al7xxx, so the critical cooling rate is chosen as 5×10^5 K/s. The lower limit of Sc and Zr for the Al6xxx are 0.46% and 0.23%, respectively.

[0085] The upper limit depends on the size of the $Al_3(Sc, Zr)$ phase. When the radius of the Al_3Sc is larger than 40 nm, the coherence relationship with the matrix will change to semi-coherence, which will lose the efficiency acting as the nucleation site. The growth of the phase can be calculated according to Lifshitz-Slyozov-Wagner theory:

$$r(t)^3 - r_0^3 = Kt \quad (7)$$

where K is the coarsening rate constant, which can be calculated by:

$$K = \frac{8C_\alpha(1-C_\alpha)\gamma D V_m}{9RT(C_\beta - C_\alpha)^2} \quad (8)$$

$$K = \frac{8\gamma V_m}{9\Lambda} \quad (9)$$

$$\Lambda = \frac{\Delta C_x}{D_x}\left(\Delta C_x G''_{xx} + \Delta C_y G''_{xy}\right) + \frac{\Delta C_y}{D_y}\left(\Delta C_x G''_{xy} + \Delta C_y G''_{yy}\right) \quad (10)$$

$$G''_{xx} = \frac{RT(1-C_y^\alpha(\infty))}{C_x^\alpha(\infty)(1-C_x^\alpha(\infty)-C_y^\alpha(\infty))} \quad (11)$$

$$G''_{xy} = \frac{RT}{(1-C_x^\alpha(\infty)-C_y^\alpha(\infty))} \quad (12)$$

where γ is the interfacial energy between the matrix and the precipitate, which can be calculated by Thermos-calc software; V_m is the molar volume. When calculating the growth of the precipitate which only consists of Al and one other element i, Eq. (8) was used, where C_α and C_β are the concentration of element i in liquid and in the precipitate. When the precipitate contains 2 alloy elements, Eq. (9) was used. $\Delta C_i = C_i^\beta(\infty) - C_i^\alpha(\infty)$. $C_i^\alpha(\infty)$ and $C_i^\beta(\infty)$ are the concentration of element i in liquid and in the precipitate. The nucleation sequence is $Al_3Zr \rightarrow Al_3(Sc,Zr) \rightarrow$ α-Al. The calculation follows this sequence, which means the Al_3Zr size will be first calculated and then $Al_3(Sc,Zr)$ will nucleate on the surface of Al_3Zr. The colliding between the particles will not be considered. Meantime, the effect of the $Al_3(Sc,Zr)$ on the viscosity will be ignored in this part. As the cooling rate during GA process is slower than that during LPBF, the GA process will be considered. The cooling rate will be decided by:

$$SDAS = 0.14d^{0.61} \quad (13)$$

$$SDAS = 38.4\dot{T}^{-0.33} \quad (14)$$

$$SDAS = 63\dot{T}^{-0.33} \quad (15)$$

where SDAS is secondary dendrite arm spacing, d is the powder size, which equals 38 μm during the calculation. For Al6xxx, Eq. (14) was used, for Al7xxxx, Eq. (15) was used. Al5.5Zn2.3Mg1.2Cu and Al1.1Mg0.55Si0.3Cu were chosen as the representatives for original Al6061 and Al7075.

[0086] The calculation results for the upper limits for Al6xxx and Al7xxx are shown in FIG. 4 and FIG 5, respectively. Based on the above a proposed chemical composition of the present disclosure is as listed in Table 1. The proposed chemical compositions have a narrower range as compared with that of the Airbus IP.

[0087] Table 1: proposed chemical compositions for Al6xxx and Al7xxx

Component	Al	Zn	Mg	Cu	Cr	Si	Sc	Zr	Others
Airbus EU	Balance	4-10%	1.0-3.5%	0-2.5%	0-0.3%	0-0.5%	0.02-1.25%	0.001-0.5%	Mn:0-0.05%
									Ti: 0-0.2%
									O: <0.1%
									Others total: <0.5%
Ref. [1]	Balance	6.04%	1.87%	0	-	-	0.81%	0.23%	-
Ref. [2]	Balance	5.36%	2.2%	2.09%	-	0.08%	0.46%	0.25%	Fe: 0.09%
Proposed A17xxx	Balance	5.5-7%	2.3-3.2%	1.2-2.0%	0-0.28%	<0.2%	0.35-1.04%	0.15-0.52%	Fe: <0.2%
									Mn: ≦ 0.1%
									Ti: ≦ 0.1%
									Ni: ≦ 0.01%
									Pb: ≦ 0.01%
									Sn: <0.01%
									V:<0.01%
									O:<0.03%
									N:<0.01%
									H:<0.001%
									Others total: ≦ 0.15%
Proposed Al6xxx	Balance	<0.25%	0.8-1.4%	0.15-0.4%	0.04-0.45%	0.4-1.0%	0.46-0.80%	0.15-0.40%	Fe: <0.2%
									Mn: <0.15%
									Ti: <0.15%
									Others total: ≦ 0.15%

[0088] In Table 1, Ref. [1] refers to: "Zhou, L., Pan, H., Hyer, H., Park, S., Bai, Y., McWilliams, B., Cho, K., & Sohn, Y. (2019). Microstructure and tensile property of a novel AlZnMgScZr alloy additively manufactured by gas atomization and laser powder bed fusion. Scripta Materialia, 158, 24-28". Furthermore, Ref. [2] refers to: "Zhu, Z., Ng, F. L., Seet, H. L., Lu, W., Liebscher, C. H., Rao, Z., Raabe, D., & Nai, S. M. L. (2022). Superior mechanical properties of a selective-laser-melted AlZnMgCuScZr alloy enabled by a tunable hierarchical microstructure and dual-nanoprecipitation. Materials Today, 52, 90-101".

[0089] Electrode Induction-Melting Gas Atomization (EIGA) is one of the powder atomization

methods capable of producing spherical, low-porosity metallic powder with minimal Oxygen pick-up. This method of atomization is suitable to produce powders of both reactive and non-reactive metallic material and the quality of the powders produced can be effectively used for AM. The EIGA set-up is used to atomize the designed Al6xxx and Al7xxx alloys.

[0090] The atomization process is controlled by two key parameters: (1) atomizing power and (2) atomizing gas pressure. For Al6xxx alloys, the atomizing power used was 20, 22, and 25 kW; the atomizing gas pressure used was 35, 40, and 45 bar. In addition, to prevent back-flow of molten material, the chamber-tower pressure differential must be maintained at >120 mbar. The electrode used had a length of up to 500 mm and a diameter of 50 mm. For other parameters, the gas temperature is 80 ºC and the nozzle gap is 0.66-0.68 mm.

[0091] FIG. 6 shows the effect of gas pressure and heating power on the yield of the gas atomization process, which is determined by the original electrode's weight, the total weight of the atomized powder, and the weight of the powder which is sieved down to <150 μm. The sieved yield improves significantly with the increased gas pressure but is minimally affected by the heating power. FIG. 7 shows the effect of gas pressure and heating power on the powder size (powder particle size) distribution. The powder particle size distribution of the aluminum alloy powder of the present invention is obtained by a laser diffraction type particle size distribution measurement device. In the cumulative distribution curve showing the relationship between the particle size and the volume cumulative distribution from the small particle size side, a particle size D10 corresponding to a cumulative frequency of 10 volume%, a particle size D50 corresponding to a cumulative frequency of 50 volume%, and a particle size D90 corresponding to a cumulative frequency of 90 volume% are measured. FIG.7 shows the powder particle size is 43 μm or more and 75 μm or less in D50, 17 μm or more and 31 μm or less in D10, and 82 μm or more and 142 μm or less in D90. With the increase in the gas pressure, the powder size decreases. The powder particle size distribution is minimally affected by the heating power. FIG. 8 shows the powder particle size distribution of the powder atomized with 45 bar gas pressure. Over 67% of the atomized powders are within the range of 20-63 μm, which is suitable for LPBF. FIG. 9 shows the effect of heating power on the powder morphology. The results indicate that there is no significant effect from the heating power within the test range. Over 70% of the powders are spherical. Hence, 20-25 kW of the heating power, 45 bar of the gas pressure are suitable for the process. The SEM image of the powders is shown in FIG. 10, demonstrating the sphericity of the powders. The chemical compositions of the atomized powders and additive manufactured products (or printed coupons) are listed in Table 2.

[0092] Table 2: Chemical compositions of the proposed Al6xxx powders, gas atomized (GA) powders and laser powder bed fusion (LPBF) additive manufactured products.

Component	Al	Mg	Cu	Cr	Si	Sc	Zr	Fe	Mn	Ti
Proposed Al6xxx	Balance	0.8-1.2%	0.2-0.3%	0.04-0.35%	0.4-0.8%	0.46-0.72%	0.15-0.36%	<0.1%	<0.15%	<0.15%
GA Powder (experimental)	Balance	1.11%	0.3%	0.21%	0.68%	0.5%	0.24%	0.03%	<0.01%	0.02%
LPBF additive manufactured product (experimental)	Balance	0.94%	<0.31%	0.25%	0.52%	0.53%	0.27%	0.054%	<0.01%	0.011%

[0093] For Al7xxx alloys, the atomizing power used were 22, 25, and 28 kW; the atomizing gas pressure used were 45 bar. In addition, to prevent back-flow of molten material, the chamber-tower pressure differential must be maintained at >120 mbar. For other parameters, the gas temperature is 80 ºC and the nozzle gap is 0.66-0.68 mm.

[0094] FIG. 11 shows the effect of heating power on the yield and the powder size (powder particle size) distribution. The sieved yield and the powder size are minimally affected by the heating power. However, it can be observed that powder atomized under 28 kW has a lower sieved yield. FIG. 12 shows the powder size (powder particle size) distribution. About 50% of the atomized powders are within the range of 20-63 μm, which is suitable for LPBF. FIG. 13 shows the effect of the heating power on the powder morphology. The results indicate that there is no significant effect from the heating power within the test range. Over 70% of the powders are spherical. Hence, 20-25 kW of the heating power, 45 bar of the gas pressure are suitable for the process. The SEM image of the powders is shown in FIG. 14, demonstrating the sphericity of the powders. The chemical composition of the atomized powders is listed in Table 3. The chemical composition of the experiment slightly shifts out of the proposed chemical composition range. The Sc content is equal to the lower limit of the proposal composition, while the Zr content is lower than the lower limit of the proposed composition. The lack of Zr suggests that the ability of grain refinement is poor. FIG. 15 shows the EBSD results of the samples printed using the powder under an ultra-low scan speed (low cooling rate). The insufficient ultrafine grains prove the poor grain refinement ability, which is associated with the crack. This result indicates that the presence of adequate Sc/Zr in the powder is essential, which ensures the production of crack-free samples through the LPBF process.

[0095] Table 3: Chemical compositions of the proposed GA and Al7xxx powders

Component	A1	Zn	Mg	Cu	Cr	Si	Sc	Zr	Fe	Others
Proposed Al7xxx	Balance	5.5-7%	2.3-3.2%	1.2-2.0%	0-0.28%	<0.2 %	0.4-1.04 %	0.2-0.52 %	<0.2 %	Mn: ≦ 0.1%
										Ti: ≦ 0.1%
										Ni:≦ 0.01%
										Pb:≦ 0.01%
										Sn: <0.01%
										V: <0.01%
										O: <0.03%
										N<0.01%
										H<0.001 %
										Others total: ≦ 0.15%
GA Powder (experimental)	Balance	7.74 %	2.91 %	2.19 %	<0.01 %	0.02%	0.40 %	0.17 %	0.04%	Mn: <0.01%
										Ti: <0.01%
										Ni: <0.01%
										Pb: 0.015%
										Sn: <0.01%
										V: <0.01%
										O: 0.041%
										N: 0.016%
										H: 0.006%

[0096] The alloy powder having the above-described composition is prepared as an alloy powder serving as a raw material for an additive manufactured product according to the present embodiments. The chemical composition of the additive manufactured product is basically the same as the chemical composition of the alloy powder.

[0097] An embodiment of an additive manufacturing method using the above-described alloy powder as the raw material will be described. The additive manufacturing method according to the present invention is a method for manufacturing an additive manufactured product by the following steps, including: irradiating the above-described Al-based alloy powder with an electron beam or a laser beam for melting and solidification to build the product. One of the characteristics is that the powder sample is melted and solidified by irradiating it with an electron beam or a laser beam.

[0098] FIG. 16 illustrates a schematic configuration of a laser additive manufacturing method, in which additive manufacturing is performed using a laser as a heat source, in the powder bed fusion coupling method. As shown in FIG. 16, 1 is an alloy powder serving as a raw material, 2 is a powder supply stage, 3 is a coat blade, 4 is a laser oscillator, 5 is a laser beam, 6 is a galvanometer devise, 7 is a build component (additive manufactured component), and 8 is a build stage.

[0099] In the additive manufacturing method, the powder supply stage 2 is elevated by a predetermined distance, the build stage 8 is lowered by a predetermined distance, and the coat blade 3 is moved in the X-direction to supply the alloy powder 1 onto the build stage 8. The laser beam 5 from the laser oscillator 4 is controlled by the galvanometer devise 6 and applied to the alloy powder in the supplied region, and the alloy powder is selectively melted and solidified to build a solidification layer. By repeating this process, a three-dimensional built component 7 (additive manufactured product) is built.

[00100] The embodiment in which irradiation is performed with an electron beam or a laser beam for melting and solidification to build the product can also be applied to both a PBF coupling method and a DED method which are additive manufacturing methods (referred to as AM methods in the present invention) for metallic materials.

[00101] In the additive manufacturing method of the present disclosure, using the PBF method as an example, the method may include the following steps:

[00102] Step 1: an optional preheating step, wherein a base plate is heated to a preheating temperature in a range of 25°C to 200°C to preheat an alloy powder (e.g. the aluminum alloy powder) that is spread on the base plate. In some embodiments, the preheating temperature is preferably in a range of 50°C to 200°C, and further preferably in a range of 100°C to 200°C.

[00103] Step 2: an additive manufacturing step, wherein the alloy powder spread on the base plate is irradiated with a heat source, so that the alloy powder is selectively melted and solidified to build a solidification layer, and repeating this process to build the additively manufactured product.

[00104] Step 3: an optional post-processing step, such as a heat-treatment step wherein a heat treatment process is performed on the additively manufactured product under specified conditions.

[00105] In the additive manufacturing method of the present disclosure, a laser or an electron beam is used as a heat source in a powder bed fusion coupling method in the additive manufacturing step (step 2). In some embodiments, the conditions for the additive manufacturing step may be, for example, forming a layer thickness of 0.01 to 0.1 mm, using an electron beam

power or laser power of 50 to 1,000 W, a scanning speed of 100 to 5,000 mm/s, and a scanning interval of 0.05 to 0.5 mm. For the purpose of improving the molding accuracy or preventing an un-melted Al-based alloy powder, the demonstration conditions include forming a layer thickness of 20 to 50 μm, an electron beam power or laser power of 100 to 500 W, a scanning speed of 600 to 1,200 mm/s, and a scanning interval of 0.05 to 0.12 mm.

[00106] In some embodiments, by using the additive manufacturing method including at least Step 1 and Step 2 mentioned above, the obtained additively manufactured product will include the following mechanical properties. For example, the tensile strength in the X-Y direction may be 290MPa or more, and although not particularly limited. For example, the yield strength in the X-Y direction may be 265MPa or more, and although not particularly limited, the upper limit of the yield strength may be 300MPa. For example, the elongation in the X-Y direction may be 10% or more, and although not particularly limited, the upper limit of the elongation may be 25%. In some embodiments, a porosity of the obtained additively manufactured product is 2.0% or less, preferably 1.0%, and more preferably 0.5%.

[00107] In some embodiments, by using the additive manufacturing method including at least Step 1 and Step 2 mentioned above, the obtained additively manufactured product will include the following physical properties. For example, the thermal conductivity (W/m・K) is 100 (W/m・K) or more and not more than 120 (W/m・K) at room temperature, is in a range of 120 to 140 (W/m・K) at 100 °C, is in a range of 130 to 150 (W/m・K) at 200 °C, and is in a range of 140 to 170 (W/m・K) at 300 °C.

[00108] In some embodiments, the optional post-processing step/heat treatment step (step 3) includes a heat treatment process such as direct aging (DA) with a temperature ranging from 250°C to 450°C, with a duration from 5 minutes to 100 hours. In some other embodiments, the optional heat treatment step (step 3) includes a heat treatment process such as solution + aging treatment (STA), which includes solution treatment at high temperatures (460 to 550 °C) for 5 minutes to 10 hours, water quenching, and then subjecting to aging treatment at low temperatures (140 to 220 °C) for 30 minutes to 100 hours.

[00109] In some embodiments, when the Neutral salt spray (NSS) test is measured in accordance with ISO 9227(JIS Z 2371), the corrosion weight loss values (g/m^2) is 4.5 g/m^2 or less, which has the same performance as the conventional material Al6061.

[00110] Examples:

[00111] In the following example, five samples of aluminum alloy powders (P1~P5) are prepared, and five samples of additively manufactured products (B1~B5) are manufactured using the aluminum alloy powders (P1~P5), and their respective compositions are illustrated in Table 4 below. The compositions of the additively manufactured products B1, B4~B5 are not measured, and their composition should approximately correspond to the compositions of the powders (P1, P4~P5). The aluminum alloy powders P1 and P5 include Sc and Zr that are used in an amount outside the scope of the present disclosure, while the aluminum alloy powders P2~P4 includes elements within the scope of the present disclosure. For all the additively manufactured products B1~B5, they are "as-built" sample, without performing further heat treatment (step 3). The additive manufacturing product was manufactured under the following conditions. Specifically, an additive manufacturing apparatus EOS M290 (LPBF method) was used for the additive manufacturing method, whereby the additive manufacturing conditions includes: preheating temperature in a range of 25°C to 200°C, an energy density in a range of 100 J/mm^3 to 200 J/mm^3, and a layer thickness of approximately 0.03mm. The energy density is set by using the following formula:

$$\text{energy density}(J/mm^3) = \text{laser power (W)}/(\text{scanning speed (mm/s)} \times \text{scanning pitch (mm)} \times \text{layer thickness (mm)}).$$

[00112] Table 4: Compositions of the aluminum alloy powders and additively manufactured products

No.		No.1		No.2		No.3		No.4		No.5	
		P1	**B1**	**P2**	**B2**	**P3**	**B3**	**P4**	**B4**	**P5**	**B5**
wt. %	**Mg**	1.00	Not measured	1.11	0.94	1.03	0.90	1.15	Not measured	1.14	Not measured
	Si	0.67		0.65	0.52	0.69	0.67	0.62		0.66	
	Sc	0.18※		0.5	0.53	0.62	0.62	0.66		0.88※	
	Zr	0.10※		0.24	0.27	0.31	0.31	0.36		0.45※	
	Fe	0.05		0.03	0.054	0.13	0.13	0.12		0.10	
	Cu	0.24		0.3	<0.31	0.33	0.34	0.29		0.25	
	Cr	0.14		0.21	0.25	0.30	0.30	0.21		0.20	

	Ti	0.004		0.02	<0.011	0.0041	0.0064	Trace		Trace	
	Mn	<0.01		<0.01	<0.01	0.0023	0.0024	Trace		Trace	
	N	0.004		0.004	-	-	-	-		-	
	O	0.02		0.03	<0.1	-	-	-		-	
	C	-		-	-	-	-	-		-	
	S	-		-	-	-	-	-		-	
	Al	Bal.		Bal.	Bal.	Bal.	Bal.	Bal.		Bal.	

※ values outside the scope of the present disclosure

[00113] Evaluation results of the powder properties of the aluminum alloy powder (P1~P5) are shown in Table 5 below.

[00114] Table 5: Evaluation results of the powder properties

No.	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)	Spherical (%)
P1	20.2	38.7	63.6	73.2
P2	16.4	32.2	53.4	78.8
P3	12.9	28.6	48.7	79.4
P4	16.8	33.2	56.3	71.5
P5	14.3	30.4	52	76.6

[00115] From the results and comparison shown in Table 5 above, it can be seen that the aluminum alloy powders (P1～P5) have a particle size in which the volume median diameter (D_{50}) is approximately 28 to 39 μm, D_{10} is approximately 14 to 21 μm and D_{90} is approximately 52 to 64 μm. In addition, for all the aluminum alloy powders (P1～P5), it was found that the circularity was more than 71.5%, and the non-spherical degree was 29% or less.

[00116] For the obtained additively manufactured products (B1~B5), the mechanical properties, the absence/presence of cracks, and porosity of the samples are evaluated, and the results are shown below.

[00117] Specifically, the mechanical properties are measured in accordance with ASTM E8/E8M-13a.

[00118] Evaluation results of the mechanical properties of the additively manufactured products B1~B5 are shown in Table 6 below, and the mechanical properties of conventional Al6061 materials are shown in Table 7 for comparison. Furthermore, the results of crack evaluation and porosity of the additively manufactured products B1~B5 are shown in Table 8 below.

[00119] Table 6: Evaluation results of the mechanical properties of the additively manufactured products (B1~B5)

No.	Ultimate Tensile Strength (MPa)		Yield Strength (MPa)		Elongation (%)	
	X-Y	Z	X-Y	Z	X-Y	Z
B1	107	-	-	-	0.69	-
B2	317	-	270	-	23.9	-
B3	292	281	279	255	14.8	11.4
B4	302	287	299	269	11.2	10.8
B5	344	327	246	318	6.0	10.1

[00120] Table 7: The mechanical properties of conventional Al6061 material (standard material)

No.	Ultimate Tensile Strength(MPa)	Yield Strength(MPa)	Elongation(%)
Reference ASTM Al6061-0	150	85	16
Reference ASTM Al6061-T4	205	110	16
Reference ASTM Al60601-T6	290	240	10

[00121] Table 8: Crack evaluation and porosity of the additively manufactured products (B1~B5)

No.	B1	B2	B3	B4	B5
Cracking (Yes/No)	Yes (FIG. 17)	No (FIG. 18)	No (FIG. 19)	No (FIG. 20)	No (FIG. 21)
Porosity (%)	2.13	**0.05**	0.06	0.03	0.01

[00122] From the results and comparison shown in Table 6 above, it can be seen that the additively manufactured products B2~B4 exhibited excellent mechanical properties for tensile strength, yield strength and elongation. In comparison, as shown in the additively manufactured product B1, the mechanical properties were inferior, and crack was observed in the manufactured product. The reason for this was that B1 uses a powder composition P1, which includes Sc/Zr in amounts outside the scope of the present disclosure (Sc: 0.46~0.80 mass%; Zr: 0.15~0.4 mass%). Furthermore, as shown in the additively manufactured product B5, when Sc/Zr are included in amounts higher than the scope of the present disclosure, although the tensile strength is high, the yield strength and elongation will also be lowered as compared to the additively manufactured products B2~B4 (including composition within the scope of the present disclosure).

[00123] In addition, by further comparison with the mechanical properties of conventional A6061 material shown in Table 7, it can be seen that the mechanical properties of the additively manufactured products B2~B4 are further improved as compared to the conventional materials. Moreover, as shown in Table 8, it can be seen that the porosity of the additively manufactured products B2~B5 are further lowered as compared with the additively manufactured product B1. The additively manufactured products B2~B4 are also shown to be crack-free (see FIGs. 18-20).

[00124] The reasons for the crack-free is due to the formation of the ultrafine grains in the melt pool boundaries, which interferes with the epitaxial growth of the long columnar grains in the alloys without the additional modification, decreasing the crack sensitivity. Further evaluation of the microstructures, and the effects of performing heat treatments was evaluated by using the aluminum alloy powder P2 as an example.

[00125] By using the aluminum alloy powder P2 as the raw material (composition including elements within the claimed range), the microstructures of the as-built additively manufactured product (without further heat treatment) are further evaluated and shown in FIG. 22 and FIG. 23. The two examples demonstrate distinct ultrafine grain fractions, which corresponding to a relatively low energy density (FIG. 22) and a relatively high energy density (FIG. 23). The ultrafine grain size is less than 1 μm.

[00126] The microhardness of the samples demonstrated in FIG. 22 and FIG. 23 are 84-103 $HV_{0.1}$. The tensile properties of the samples demonstrated in FIG. 22 and FIG. 23 are listed in Table 9.

[00127] Table 9: Tensile properties of the as-built (additive manufactured) samples.

Sample	Yield strength (MPa)	Ultimate tensile strength (UTS) (MPa)	Total elongation (%)
Example E1	265-270	316-318	23-25
Example E2	294-310	322-334	20-22

[00128] The strengthening contribution for the as-built samples comes from the grain boundaries the most. The precipitates will provide one of the major parts for the strength of aluminum alloys. Therefore, precipitate manipulation is important for controlling the properties. The manipulation of the precipitates is realized by the heat treatment control. There are two ways to program the heat treatment for this alloy, which includes DA and STA as mentioned above.

[00129] (1) Relying on the precipitates which consist of additional elements, i.e., Sc and Zr, the precipitate will be $Al_3(Sc,Zr)$. To achieve this, moderate temperature (250 to 450 °C) needs to be applied. The duration can change from 5 mins to 100 h, depending on the original microstructure

and which properties are needed. This method is referred as direct aging (DA).

[00130] (2) Relying on the precipitate which consist of original elements, i.e., Mg and Si, the precipitate will be Mg_xSi_y. To achieve this, the solution treatment needs to be applied first. The solution treatment is performed at high temperature (460 to 550 °C) for 5 mins to 10 h. After holding, the parts will be water quenching. After solution treatment, the parts will be subjected to aging treatment, which will be performed at low temperature (140 to 220 °C) for 30 mins to 100 h. This method is referred as solution + aging treatment (STA).

[00131] When DA is conducted on the sample of example E2, the DA is being held at 400 °C for 1 h (referred as example E3), the TEM results in FIG. 24 show the coherent secondary $Al_3(Sc,Zr)$ as the strengthen phase in the samples. When STA is conducted on the sample of example 2, the STA is being held at 550 °C for 0.5 h, water quenched, and then being held at 175 °C for 8 h (referred as example E4), the TEM results in FIG. 25 show the needle-liked precipitates nucleate in the samples. These needle-liked precipitates are Mg_xSi_y.

[00132] The microhardness of the DA samples depends on the temperature and duration. The highest microhardness can be larger than 120 $HV_{0.1}$. The microhardness of the STA samples depends on the temperature and duration. Example E4 shows a microhardness of ~110 $HV_{0.1}$.

[00133] The tensile property examples of the heat-treated samples are listed in Table 10 below. Besides example E3 and example E4, the following examples are also included for comparison:

[00134] Example E5: sample with the microstructure shown in Example E1 – Direct aging at 400 °C for 1 h.

[00135] Example E6: sample with the microstructure shown in Example E1 – Solution treated at 520 °C for 0.5 h, water quenched, and then being held at 175 °C for 8 h.

[00136] Table 10: Tensile properties of the heat-treated samples.

Sample	Yield strength (MPa)	Ultimate tensile strength (UTS) (MPa)	Total elongation (%)
Example E3 (DA)	348-378	358-391	8-12
Example E4 (STA)	288-300	334-344	13-17
Example E5 (DA)	321-327	345-351	17-23
Example E6 (STA)	331-335	373-377	13-15

[00137] By comparing the microstructures and tensile properties shown in Table 10 above, the strengthening mechanism for the heat-treated samples depend on the contribution from both the grain-boundary strengthening and the precipitate strengthening. For DA samples, coherent secondary $Al_3(Sc,Zr)$ precipitates are the main contributors. For STA samples, coherent $Al_3(Sc,Zr)$ and needle-liked precipitates are the main contributors.

[00138] Based on the examples above, for the as-built additively manufactured product (without further heat treatment) using the LPBF process, the bi-modal grain size distribution with ultrafine grains with the size less than 1 μm and possible columnar grains with the size larger than 1 μm can be obtained, and microhardness of 84 $HV_{0.1}$ or higher can be achieved. Furthermore, when the designated amounts of aluminum, magnesium, copper, chromium, silicon, scandium, and zirconium are included in the aluminum alloy powder P2, which is used as a raw material for manufacturing the additively manufactured product, the obtained product will be crack-free, the yield strength and ultimate tensile strength will be 250 MPa or higher, and the elongation will be 16% or higher.

[00139] For the DA treated samples, nanosized $Al_3(Sc, Zr)$ precipitates are observed with a transmission electron microscopy, which are the main strengthening precipitates in this state, and the ultrafine grains are maintained to be 1 μm or less. Similarly, for DA treated samples, the yield strength and ultimate tensile strength will be 300 MPa or higher, and the elongation will be 3% or higher. For STA treated samples, nanosized $Al_3(Sc, Zr)$ precipitates and needle-liked precipitates are observed with the transmission electron microscopy, which are the main strengthening precipitates in this state, and the grain size ranges from 100 nm to 200 μm. Similarly, for STA treated samples, the yield strength is 270 MPa or higher, while the ultimate tensile strength is 330 MPa or higher.

Industrial Applicability:

[00140] The alloy powders (Al6xxx and Al7xxx) and laminated molded product (additive manufactured product) of the present disclosure can be used in different engineering applications, ranging from aerospace, automobile and semiconductor to marine and defense industries.

CLAIMS

WHAT IS CLAIMED IS:

1. An aluminum-based composition, consisting of:

magnesium, copper, chromium, silicon, scandium, and zirconium; and

one or more other metals which are not aluminum, magnesium, copper, chromium, scandium, and zirconium, with remainder being aluminum containing unavoidable impurities; and

wherein, based on a total amount of the aluminum-based composition, the aluminum-based composition contains:

0.46 mass% to 0.80mass% of the scandium,

0.15 mass% to 0.40 mass% of the zirconium,

0.8 mass% to 1.4 mass% of the magnesium,

0.15 mass% to 0.4 mass% of the copper,

0.04 mass% to 0.45 mass% of the chromium,

0.4 mass% to 1.0 mass% of the silicon, and

the other metals contain iron, manganese, and/or titanium.

2. The aluminum-based composition according to claim 1, wherein

the aluminum-based composition contains:

0.5 mass% to 0.72 mass% of the scandium, and

0.24 mass% to 0.36 mass% of zirconium.

3. The aluminum-based composition according to claim 1 or 2, wherein the aluminum-based composition contains 0.14 mass% to 0.45 mass% of the chromium.

4. The aluminum-based composition according to claim 1 or 2, further comprising less than

0.25 mass% of zinc.

5. An aluminum-based composition containing:

aluminum, zinc, magnesium, copper, chromium, scandium, and zirconium, with remainder consisting of aluminum and unavoidable impurities,

wherein the aluminum-based composition contains:

0.35 mass% to 1.04mass% of the scandium,

0.15 mass% to 0.52 mass% of the zirconium,

5.5 mass% to 7.0 mass% of the zinc,

2.3 mass% to 3.2 mass% of the magnesium,

1.2 mass% to 2.0 mass% of the copper, and

0.28 mass% or less of the chromium.

6. The aluminum-based composition according to claim 5, further containing silicon present in an amount of less than 0.2 mass%.

7. An aluminum alloy powder containing the aluminum-based composition according to claim 1.

8. An aluminum alloy powder containing the aluminum-based composition according to claim 5.

9. An aluminum alloy additive manufactured product manufactured by using the aluminum alloy powder according to claim 7.

10. An aluminum alloy additive manufactured product manufactured by using the aluminum alloy powder according to claim 8.

11. A method of forming an aluminum alloy powder, the method comprising:

induction-melting the aluminum-based composition according to claim 1 or 5 to produce a molten aluminum alloy; and

subjecting the molten aluminum alloy to gas atomization.

12. The method according to claim 11, wherein the gas atomization is carried out at at least one of the following:

(i) a pressure of 40 to 45 bar;

(ii) a power of 20 to 30 kW; and

(iii) a temperature of 60°C to 100°C.

13. A method for manufacturing an additive manufactured product, the method comprising:

a step of irradiating the aluminum alloy powder according to claim 7 or 8 with a heat source to melt and solidify the aluminum alloy powder.

14. The method according to claim 13, wherein the heat source is a heat source using a powder bed fusion method using an electron beam or laser, or a directed energy deposition method using an electron beam or laser.

15. The method according to claim 13 or 14, further comprising a preheating step of preheating the aluminum alloy powder,

wherein in the preheating step, a preheating temperature is in a range of 50°C to 200°C.