Precipitation hardening parameters effects on mechanical properties of extruded AA2014 based metal matrix composite

Shashi Prakash Dwivedi, Satpal Sharma, Raghvendra Kumar Mishra
School of Engineering, Gautam Buddha University, Greater Noida, Gautam Buddha Nagar, U.P. 201310, India

Article Info
Article history:
Received 02 April 2016
Received in revised form
20 May 2016
Accepted 28 May 2016
Available online 15 October 2016

Keywords
Solutionizing temperature, solutionizing time, aging temperature, aging time

Abstract

Heat treatment of aluminium alloys are affected by means of precipitation hardening comprising the following steps: solutionizing, quenching and aging at room temperature (natural aging) or at elevated temperature (artificial aging). Nevertheless, during precipitation hardening of aluminium matrix-based discontinuously reinforced composites, in the solutionizing stage, the matrix alloy is modified quite significantly due to the occurrence of dislocations. The main problem faced in the heat treatment process is the selection of optimum combination of precipitation of hardening parameters for achieving the required mechanical and tribological properties of composites.

1. Introduction

Metal-matrix composites are used in advanced structural, electronic, automotive, aerospace, wear applications and thermal management [1]. The advantage of metal matrix composites is their adapted physical, mechanical and thermal properties with low density, high abrasion, high thermal conductivity, high specific strength, high specific modulus, and wear resistance [2, 3].

The ever-increasing demand for low cost reinforcement encouraged the interest towards production and utilization of using by-products from industry as reinforcement since they are readily available or are naturally renewable at affordable cost. Al alloys are widely used in aerospace, automobile and electronic industries due to their excellent wear and corrosion resistance, low density, low coefficient of thermal expansion, good strength and castability. The common microstructure of hypereutectic Al- alloys is composed of primary silicon particles. The high strength and wear resistance of these alloys are attributed to the presence of hard silicon particles [6]. The forming based semi-solid phase has attracted great attention as a new technology since it complemented the shortcomings of the current forming processes. The morphology of the primary phase of semi-solid metals plays a very important role in the quality control of semi-solid process. Electromagnetic stirring is a forming process which fills the mold cavity through injecting cylinder with semi-solid slurry after uniformly transformed dendritic microstructure formed during solidification process to spherical primary-Al phase particles and distributing it into eutectic phase, by strongly stirring the melt at the initial stage of solidification. The electromagnetic stirring needs to be a good substitute system of mechanical stirring to avoid alloy contamination and damage of stirrer. The rheology forming is controlled by grain and solid fraction using the electro-magnetic stirring system. This study sets up the experimental data applicable to control the particle grain size of the resulting materials to be produced by electromagnetic stirring to investigate the relation between the properties of A356 alloy such as primary-Al phase particle sizes, their distribution, and spherical structure and electromagnetic stirring current and time [7]. The preparation of raw material slugs within the mushy zone, which is the key technology of semisolid metal processing, is an issue of great importance. In semisolid metal processes for Al alloys, it is desired that the structure be non-dendritic and contain minimal or no entrapped eutectic. The traditional EMS (Electromagnetic stirring) process mainly works in the mushy zone of the alloy, i.e., supercooled + EMS. There are two hypotheses to explain the formation mechanism of non-dendrites, that is, mechanical fragmentation and the root remelting of the dendrite arms. The homogenization of the temperature and constituents caused by the forced convection during stirring can prompt the nucleation of the primary α-Al phase and restrain the growth of dendrites. The combination of light weight, environmental resistance and useful mechanical properties such as modulus, strength, toughness and impact resistance has made aluminium alloys well suited for use as matrix materials.

In AA2014/eggshell metal matrix composite, very little study has been done to logically examine the mechanisms of atom redistribution in the precipitation hardening process and the effect of ~~a~~ variety of natural ageing times on the mechanical properties at the end of artificial ageing process.

Among the Al-Cu-Mg casting alloys, AA2014 cast aluminium alloy is a commercially accepted casting alloy. It is generally used in aircraft structures, especially wing and fuselage structures under tension. It is also used in high temperature applications such as in automobile engines and in other rotating and reciprocating parts such as piston, drive shafts, brake- rotors and in other structural parts which require light weight and high strength materials. The 2014 alloy is heat treatable in the cast condition and exhibits the highest strength to weight ratio. The chemical and mechanical properties of AA2014 alloy are given in Table 1 and Table 2 respectively [6].

2. Literature review

Review of heat treatment and its Process Parameters for the Metal Matrix Fabrication are given in Table 1.

Corresponding Author,
E-mail address: shashi_gla47@rediffmail.com

Table 1: Chemical composition of AA2014 alloy (wt %)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Cr	Al
0.5-0.9	0.5	3.9 – 5.0	0.4-1.2	0.2-0.8	0.25	0.2	0.1	0.1	Balance

Table 2: Measured properties of AA2014 alloy

Melting point	640^0C
Density (g/cm^3)	2.8
Tensile Strength (MPa)	185
Hardness (BHN)	60
Toughness (Joule)	12
Ductility (percentage elongation)	13
Fatigue Strength (MPa) for 1 x 10^7 cycles	90

Table 1: Review of heat treatment and its Process Parameters

Ref. No.	**Author's Name (Year)**	**Conclusion and Results**
11	D. Godard et al. (2002)	The precipitation sequences have been investigated during the cooling of an aluminium alloy AA 7010 from the solutionizing temperature. Interrupted quenching was performed at various temperatures and different holding times
10	S.C Sharma et al. (2002)	1. The composite samples were aged at 32, 80, 180, and 250 °C after solutionizing at 320 °C for 3 h followed by cold water quenching. 2. Reduction in hardness values was observed with increase in aging time.
12	K. Mahadevan et al. (2005)	1. Composites can be heat treated by solutionizing and aging to modify the microstructure and thereby the mechanical properties. 2. It is observed that the mechanical properties are degraded for a delay of up to 12 h before aging. However for delay of 16 h and beyond, the properties are similar to that of composites exposed to nil (0 h) delay.
13	C.H. Chiang et al. (2006)	The microstructures and mechanical properties of cast alloys in solutionized and aged conditions were studied.
14	K. Mahadevan et al. (2008)	1. Aluminium metal matrix composites are age hardenable and can be strengthened through precipitation hardening process. 2. Tests, based on the design of experiments (DOE) technique, were conducted to systematically record the influence of precipitation hardening parameters on the fatigue strength of AA 6061-SiCp composite. 3. For a given solutionizing temperature of 530 ◦C it is observed that solutionizing time (St) as an individual parameter has the maximum influence on fatigue strength of AA 6061-SiCp composite, followed by the first order interaction effect between solutionizing time (St) and aging temperature (AT).
15	I.G. Siddhalingeshwar et al. (2011)	The effect of mushy state rolling on aging kinetics of stir-cast Al–4.5Cu alloy and in situ Al–4.5Cu–5TiB2composite and their tensile behavior in solution-treated (495 °C) or differently aged (170 °C) conditions, has been investigated.
16	A. Malekan et al. (2011)	1. The effect of different solution temperatures has been investigated on the microstructure and tensile properties of Al–Mg_2Si composite specimens were subjected to solutionizing at different temperatures of 300 °C, 350 °C, 400 °C, 450 °C, 500 °C, 550 °C and 580 °C for holding time of 4 h followed by quenching. 2. Tensile test results indicated that ultimate tensile strength (UTS) gradually decreased upon solutionizing from 300 to 550 °C while further increase in the temperature followed by a sharp decrease in UTS up to 580 °C solutionizing temperature. 3. It was found that the elongation has become three times greater in comparison to the as-cast state. Elongation results showed an increase up to 500 °C and then reduced temperatures of 550 and 580 °C.
17	Pei-yue LI et al.	The optimized solution treatments for specimens with dimensions of 25 mm×25 mm×2.5 mm and 70

	(2012)	mm×60 mm×20 mm are (480 °C, 30 min) and (480 °C, 90 min), respectively.
18	Choong do Lee (2013)	Heat treatment with solutionizing and aging treatment times of 6 h at 540 °C and 16 h at 160 °C, respectively, was proposed as the optimal conditions.
20	E.M. Elgallad et al. (2014)	1. Solution treatment at 530 °C for 5 h dissolved the first three phases into the solid solution and consequently improved the mechanical properties of the alloy. 2. By utilizing the appropriate aging temperature and time, different combinations of strength and ductility could be obtained
19	Shashi shekhar et al. (2014)	Aging behaviour was studied as a function of time and temperature and corresponding microstructure as well as fractographs of tensile tested specimens was recorded.

3. Precipitation hardening process

Fabrication of metal matrix composite used in this study was fabricated by electromagnetic stir casting technique, details given elsewhere [7].

Precipitation hardening is a heat treatment technique used to increase the yield strength as well as other properties of composites. The process of precipitation hardening is actually a three step sequence. The orders of involved heat treatment process were solutionizing, hot bath quenching, aging and air-cooling as shown in Figure 1. The first step is known as solution treatment which is used to remove the room-temperature structure and redissolves any existing precipitate. Solutionizing process was done at a temperature of 530^0 C for certain range of time period and then quenched in a hot bath about 70^0C to keep away from warping of composite specimens. If the composite were slow cooled, the second – phase precipitate would nucleate and material would revert back to a structure similar to equilibrium. To prevent this from happening, the solutionized composites are quenched from their solution treatment temperature. Without delay (not more than 15 seconds), artificially aging was carried out in a muffle furnace for certain range of temperature and time.

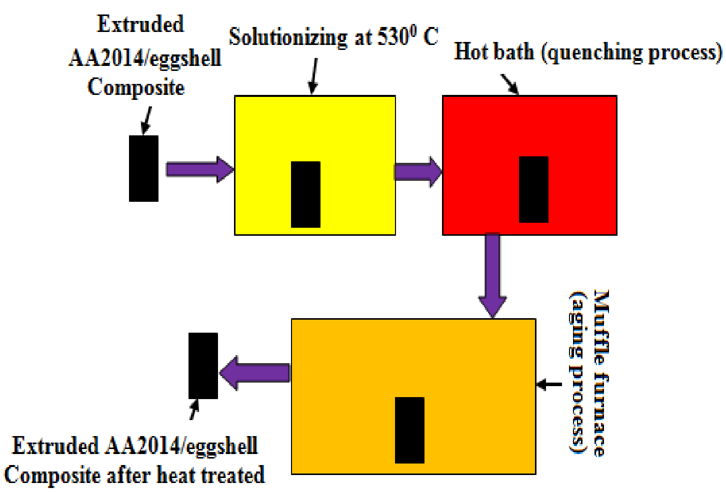

Fig. 1: Schematic diagram of Precipitation hardening process

4. Conclusions

The following conclusions can be drawn from the analysis:-

1. Composites can be heat treated by solutionizing and aging to modify the microstructure and thereby the mechanical properties.
2. By utilizing the appropriate aging temperature and time, different combinations of strength and ductility could be obtained.

References

1. S. P. Dwivedi, S. Kumar and A. Kumar, Effect of turning parameters on surface roughness of A356/5% SiC composite produced by electromagnetic stir casting, Journal of Mechanical Science and Technology, 26 (12) (2012) 3973-3979.
2. S. P. Dwivedi, S. Sharma and R. K. Mishra, Microstructure and Mechanical Properties of A356/SiC Composites Fabricated by Electromagnetic Stir Casting, Procedia Materials Science, 6 (2014) 1524 – 1532.
3. S. P. Dwivedi, S. Sharma and R. K. Mishra, Effects of roller burnishing process parameters on surface roughness of A356/5%SiC composite using response surface methodology, Adv. Manuf. 2 (2014) 303–317.
4. S.B. Hassan and V.S. Aigbodion, Effects of eggshell on the microstructures and properties of Al–Cu–Mg/eggshell particulate composites, Journal of King Saud University – Engineering Sciences, 27 (2015) 49–56.
5. E. Mosaddegh, A. Hassankhani, S. Pourahmadi and D. Ghazanfari, Ball Mill-assisted Preparation of Nano-CaCO3 as a Novel and Green Catalyst -based Eggshell Waste: A Green Approach in the Synthesis of Pyrano[4,3-b] pyrans, International Journal of Green Nanotechnology, 1 (2013) 1-5.
6. H. K. Durmus and Cevdet Meric, Age-hardening behavior of powder metallurgy AA2014 alloy, Materials and Design 28 (2007) 982–986.
7. S. P. Dwivedi, S. Sharma and R. K. Mishra, Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting, J Braz. Soc. Mech. Sci. Eng., 37 (2015) 57–67.
8. S. P. Dwivedi, Effect of process parameters on tensile strength of friction stir welding A356/C355 aluminium alloys joint, Journal of Mechanical Science and Technology, 28 (1) (2014) 285-291.
9. S. P. Dwivedi and S. Sharma, Effect of Process Parameters on Tensile Strength of 1018 Mild Steel Joints Fabricated by Microwave Welding, Metallogr. Microstruct. Anal., 3 (2014) 58–69.
10. S.C Sharma, Shanta Sastry, M Krishna, "Effect of aging parameters on the micro structure and properties of ZA-27/aluminite metal matrix composites," Journal of Alloys and Compounds, 346 (2002) 292–301.

11. D. Godard, P. Archambault, E. Aeby-Gautier, G. Lapasset, "Precipitation sequences during quenching of the AA 7010 alloy," Acta Materialia, 50 (2002) 2319–2329.
12. K. Mahadevan, K. Raghukandan, T. Senthilvelan, B.C. Pai, U.T.S. Pillai, "Studies on the effect of delayed aging on the mechanical behaviour of AA 6061 SiCp composite," Materials Science and Engineering: A, 396 (2005) 188–193.
13. C.-H. Chiang, Chi Y.A. Tsao, "Microstructures and mechanical properties of spray-formed and squeeze-cast Al–25Si–0.89Cu–1.0Ni–0.84Mg alloys in solutionized and aged conditions," Materials Science and Engineering: A, 417 (2006) 90–98.
14. K. Mahadevan, K. Raghukandan, B.C. Pai, U.T.S. Pillai, "Influence of precipitation hardening parameters on the fatigue strength of AA 6061-SiCp composite," Journal of materials processing technology, 198 (2008) 241–247.
15. A. Malekan, M. Emamy, J. Rassizadehghani, A.R. Emami, "The effect of solution temperature on the microstructure and tensile properties of Al–15%Mg2Si composite," Materials & Design, 32 (2011) 2701–2709.
16. I.G. Siddhalingeshwar, M.A. Herbert, M. Chakraborty, R. Mitra, "Effect of mushy state rolling on age-hardening and tensile behavior of Al–4.5Cu alloy and in situ Al–4.5Cu–5TiB2 composite," Materials Science and Engineering: A, 528 (2011) 1787–1798.
17. Pei-yue LI, Bai-qing XIONG, Yong-an ZHANG, Zhi-hui LI, "Temperature variation and solution treatment of high strength AA7050," Transactions of Nonferrous Metals Society of China, 22 (2012) 546–554.
18. Choong do Lee, "Effect of T6 heat treatment on the defect susceptibility of fatigue properties to microporosity variations in a low-pressure die-cast A356 alloy," Materials Science and Engineering: A, 559 (2013) 496–505.
19. Shashi shekhar, Rajdeep Sarkar, Sujoy Kumar Kar, Amit Bhattacharjee, "Effect of Solution Treatment and Aging on Microstructure and Tensile Properties of High Strength β Titanium Alloy, Ti-5Al-5V-5Mo-3Cr," Materials & Design, (2014) http://dx.doi.org/10.1016/j.matdes.2014.04.015
20. E.M. Elgallad, P. Shen, Z. Zhang, X.-G. Chen, "Effects of Heat Treatment on the Microstructure and Mechanical Properties of AA2618 DC Cast Alloy," Materials & Design, (2014). http://dx.doi.org/10.1016/j.matdes.2014.04.045