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STUDY ON TENSILE PROPERTIES AND MICROSTRUCTURES OF DIFFERENT SITES IN Al-Si ALLOY CASTING COMPONENT

The tensile properties and microstructures of ZL114A alloy component with a complex shape are investigated at room temperature and 200°C, using the tensile tests, scanning electron microscopy and electron backscattering diffraction. Both thin wall and thick structure exhibit excellent properties, of which max ultimate tensile strength and elongation at break reach 314 MPa and 2.5% at room temperature, respectively. The ultimate tensile strengths of thin wall are 40 MPa and 25 MPa greater than those of thick structure at room temperature and 200°C, respectively. Moreover, the eutectic Si phases of thin wall exhibit a predominantly spherical morphology while of the morphology of thick structure are rod-like, resulting in the different mechanical properties between thin wall and thick structure. The fracture morphologies of thin wall and thick structure are studied to explain the difference in performance between thin wall and thick structure.

Keywords: ZL114A alloy; plaster-mold casting; tensile properties; microstructure; fracture

1. Introduction

Al-Si casting alloys are also called the ZL-1XX series casting aluminum alloys, which are widely applied in automotive and aerospace industries, owing to their excellent fluidity, good mechanical properties, good corrosion resistance, etc.[1-5]. ZL114A alloy (called in China norm), a typical Al-Si casting alloy, is usually used to fabricate the casting component with complex shape and thin-wall structure. In order to ensure the quality of casting component, pressure and vacuum casting methods are employed [6,7], and the results indicate that the fitting pressure and vacuum degree can improve the tensile properties [8,9].

So far, several researchers have focused on improving the microstructure and mechanical properties of Al-Si alloy through alloying, heat treatment and other methods [10-13]. In the Al-Si alloy, the main secondary phase is the eutectic Si phase, of which the size and morphology have a significant influence on mechanical properties. Some researches declare that the large-size Si phase in the Al-Si alloy markedly deteriorates the mechanical properties [14,15], and plastic deformation will not occur in the eutectic Si phase [16]. In addition, the eutectic Si phase will be spheroidised rapidly during the solution treatment, which has a prominent effect on mechanical properties [12,17,18]. However, few studies focus on the actual mechanical properties of the Al-Si alloy casting component that is very important for engineering applications.

In present work, a ZL114A alloy casting component with thick structure (TS) and thin wall (TW) is fabricated via plaster mold method under vacuum-pressure condition. The tension specimens are cutted from the TW and TS. Then, the actual tensile properties at different temperatures and corresponding microstructures are studied through tensile test, scanning electron microscope (SEM) and electron back scattering diffraction (EBSD).

2. Experimental

The ZL114A alloy component with a dimension of Φ500×700 mm was fabricated through the plaster-mold method under pressure-vacuum environment. The main casting processing parameters and actual composition are shown in TABLE 1 and TABLE 2, respectively. The brief geometry of the ZL114A component is depicted in Fig. 1, which includes a TW with 5 mm thickness and TS with dimensions of 20×30 mm where as the sites for specimens. After the feed system is removed, X ray

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detection was employed to ensure that there are no obviously large defects in the component like shrinkage and crack. Then, the component was heated up to 535°C and soaked for 12 hours followed by quenching in warm water (60-100°C). After that, the component was heated up to 160°C for 8 hours. In order to research the mechanical properties of different structure in the component, the cylindrical specimens with Φ 6 mm (test section) and tabulate specimens with 7×3 mm (test section) were cut from the TS and TW, respectively. The dimensions of the specimen are shown in Fig. 1. These specimens are subjected to tensile tests at room temperature (RT) and 200°C (the most commonly occuring temperature in engineering field) via mechanical testing machine (HZ-1009A, manufactured by Dongguan Lixian Instrument Technology Co. Ltd.). The microstructure and the fracture surface of the tensile specimens were studied by SEM and EBSD (Zeiss, Sigma300).

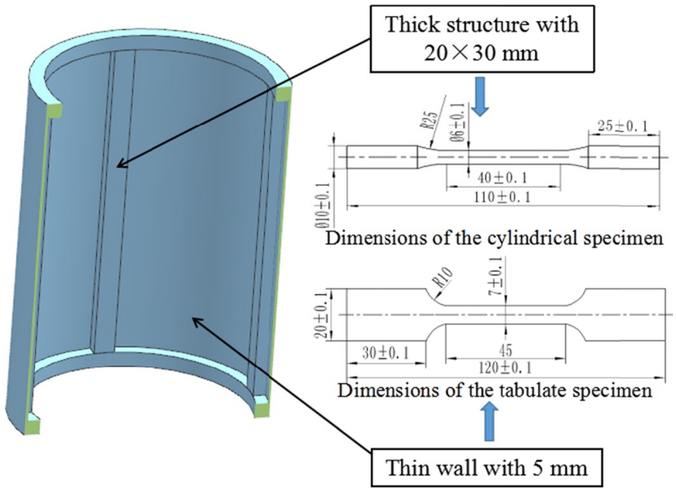

Fig. 1. The geometry of ZL114A component and dimensions of the specimens

TABLE 1

The main casting processing parameters

Parameter type	Value	Parameter type	Value
Temperature	725-730°C	Pouring time	40-45 s
Pressure	0.5 MPa	Pressure time	30 min
Vacuum degree	–0.05 MPa	—	—

TABLE 2

The actual composition of ZL114A component

Element	Al	Si	Mg	Ti	Fe	Cu	Zn	Mn
wt.%	Bal.	6.86	0.51	0.14	0.08	0.1	0.08	0.03

3. Results and discussions

3.1. Tensile properties

Fig. 2 shows the tensile properties of ZL114A alloy component at different temperatures. It is obvious that the ultimate tensile strength at RT is always higher than that at 200°C. The ultimate strengths of TW and TS at RT are 314 MPa and 274 MPa respectively, of which value decreases to 237 MPa and 213 MPa at 200°C. When subjected to a tensile test at 200°C, the high temperature can promote the movement of dislocation. Thus, the specimens exhibit softer feature. Therefore, the elongation of TW at RT is 2.5%, of which value increases to 3% at 200°C. However, it is worth noting that the elongation of TS shows opposite feature as shown in Fig. 2(b). Besides, not only strength but also elongation of TW are always better that those of TS. According to the literatures [12,14], it is possible to be attributed to the morphology, size and volume fraction of eutectic Si phase. Whatever, comparing with the tensile properties of casting specimens reported in literatures [8-12], ZL114A alloy component produced by the plaster-mold method still show excellent mechanical properties.

3.2. Microstructures and fractures

The microstructures of TW and TS after tensile test at different temperatures are shown in Fig. 3. It can be found that the eutectic Si phase is distributed in the boundary of the α-Al matrix, of which the morphology of eutectic Si phase is different for TW and TS. The eutectic Si phase of TW is spherical while that

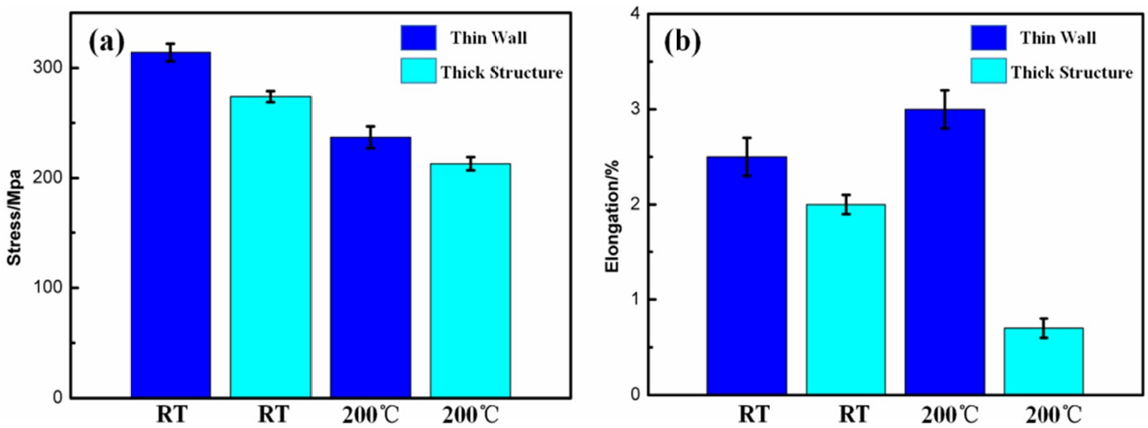

Fig. 2. The tensile properties of the present casting component under RT and 200°C, (a) ultimate strength, (b) elongation

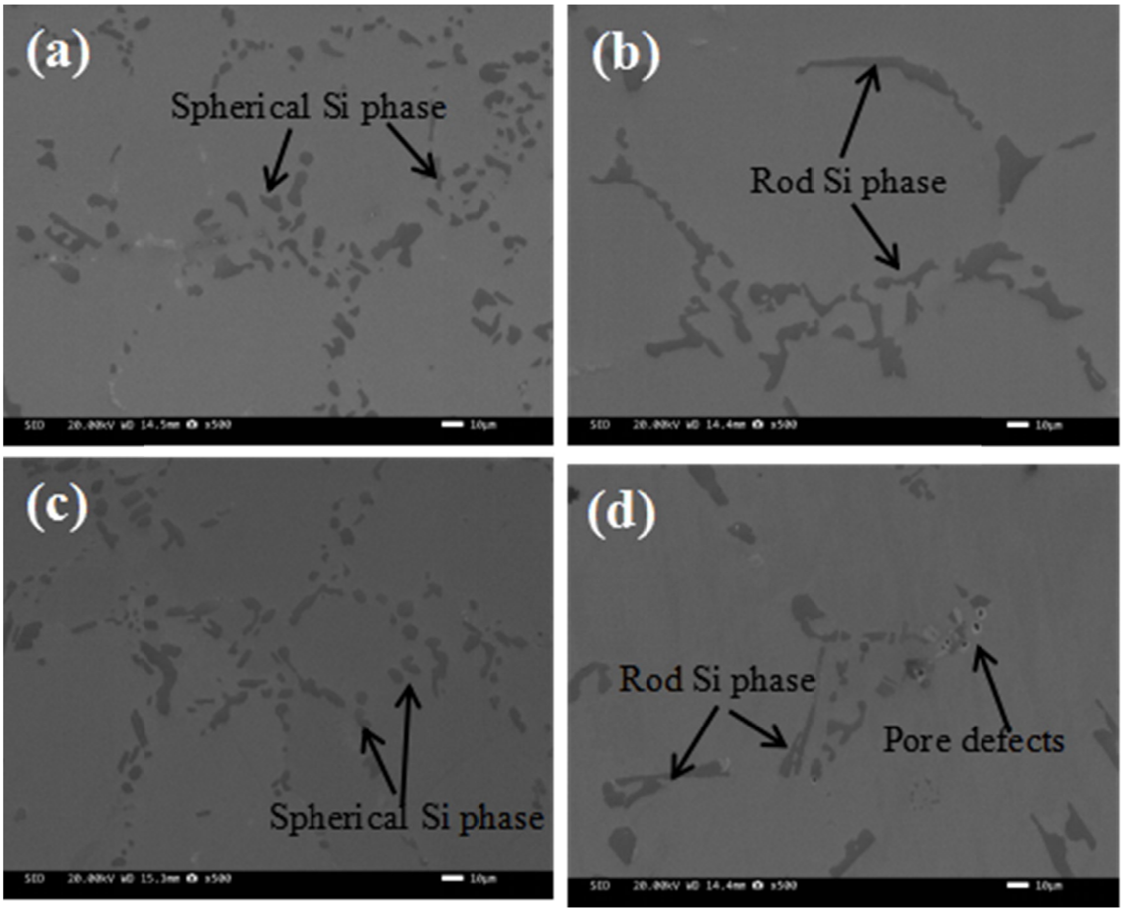

Fig. 3. Microstructures of the diffenrent sites in present casting component after tensiling, (a)(c)thin wall, (b)(d) thick structure, (a)(b) tensile at RT, (c)(d) tensile at 200°C

of TS is rod-like. The fine Si phase becomes the strengthening phase during tensile test and act as a location for pinning dislocation. Besides, the volume fraction of TW is more than that of TS. This variation in the microstructures may be ascribed to the difference in the solidification rates of TW and TS. Therefore, the mechanical properties of TW are always better than those of TS. It is worth noting that some casting defects are found in the microstructure of TS after tensile test at 200°C, as shown in Fig. 3(d). As we all known, the casting defects such as pore, shrinkage and crack do harm to mechanical properties, especially to elongation. This is the main reason for that elongation of TS at 200°C significantly decreases.

The microstructures of the TW subjected to tensile test at RT and 200°C are further analyzed via EBSD technology. It is obvious that the eutectic Si phases are in the interdendritic boundaries of α-Al matrix. According to the Kernel average misorientation (KAM) maps, the dendritic α-Al matrix possesses low dislocation density (light green color or blue color), as shown in Fig. 4(b)(d). Furthermore, the magnified maps of the white area in KAM maps show that the eutectic Si grains are free of dislocations (blue color). However, the high dislocation densities are found in the interdendritic area, i.e. the area between α-Al matrix and eutectic Si grains. During tensiling, dislocations are induced in α-Al matrix, which propagate and slip with the increase of deformation. When the dislocations move to the interdendritic area, the eutectic Si grain will pin the dislocations, result in dislocation stacking. Thus, there is low dislocation density in the α-Al matrix. At the same time, the eutectic Si phase cannot be deformed due to its high hardness. Therefore, high dislocation density only exists in the interdendritic area. This phenomenon is also found in literature [16].

Fig. 5 shows the fracture features of the TW and TS at different tensile temperatures. The fracture morphology of TW at 200°C is typically ductile, with a lot of dimples. Thus, the elongation of TW tensiling at 200°C is the highest. For TS, not only dimples but also cleavage platform exist in fracture. This may be because the cooling rate of TS is slower than that of TW, resulting in the eutectic Si phase exhibits long rod-like morphologies. Moreover, some un-syncretic casting defects are found in Fig. 5(d), which deteriorates the mechanical properties, especially elongation. This result agrees with the microstructure in Fig. 3(d).

4. Conclusions

The tensile properties and corresponding microstructures of ZL114A alloy component produced by the plaster-mold method are explored. The main conclusions are exhibited as follows:

(1) The tensile properties of the thin wall in ZL114A alloy component are better than those of thick structure, but both

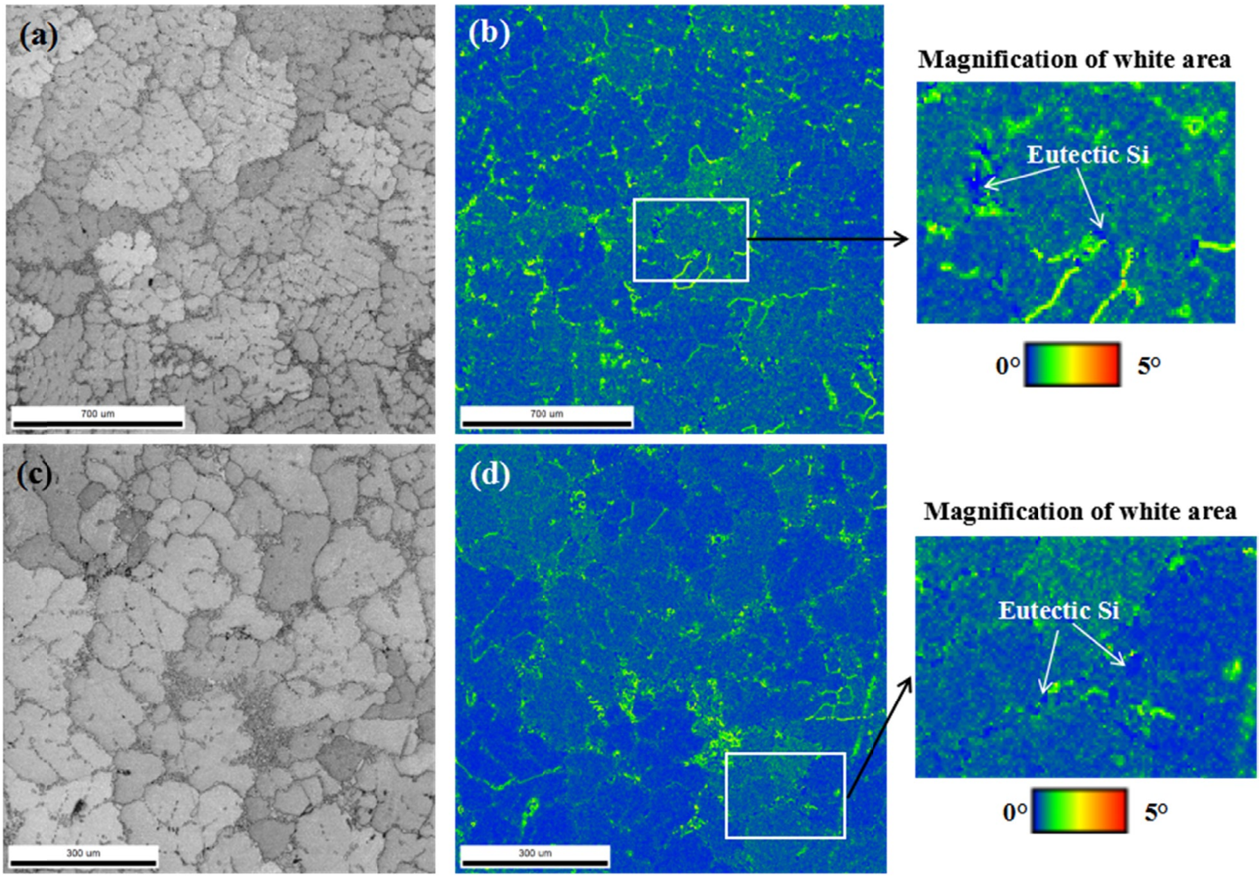

Fig. 4. EBSD maps of thin wall tensiling at different temperature, (a)(b) RT; (c)(d) 200°C; (a)(c) band contrast; (b)(d) KAM

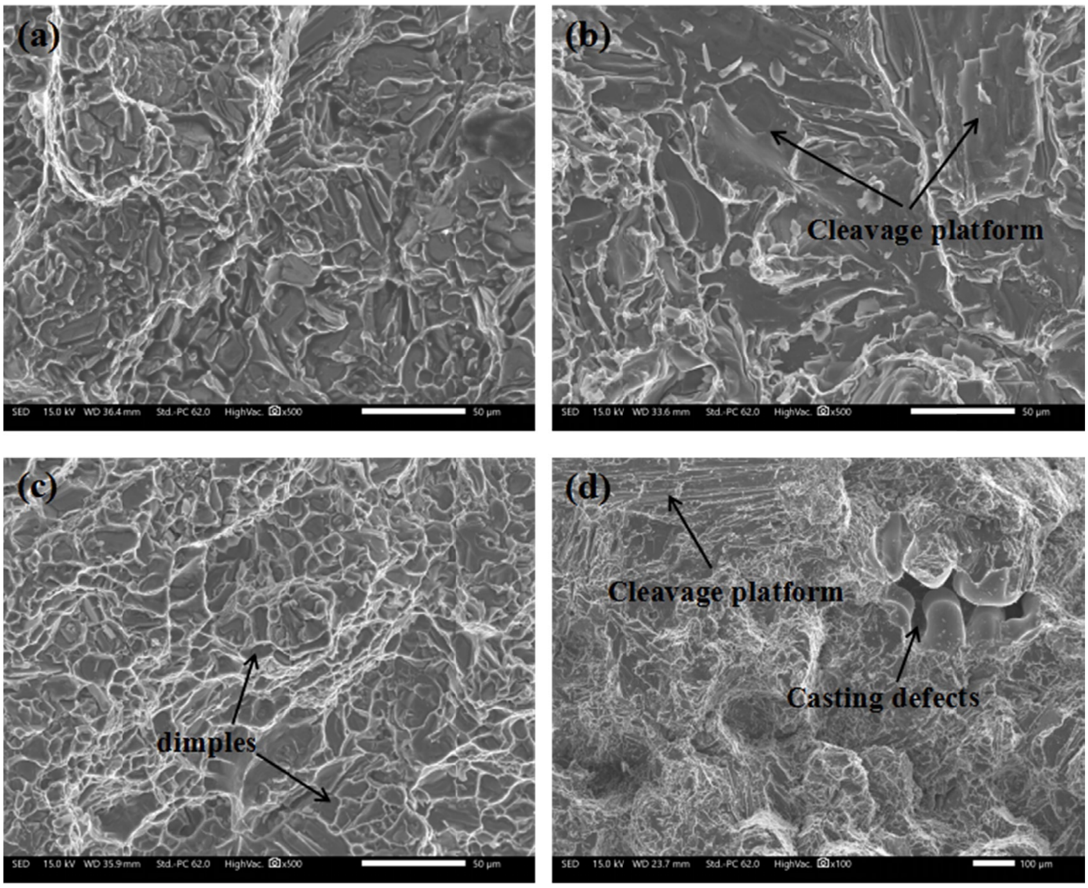

Fig. 5. Fracture of the different sites in present casting component, (a)(c) thin wall, (b)(d) thick structure, (a)(b) tensile at RT, (c)(d) tensile at 200°C

of them exhibit excellent properties. The ultimate tensile strengths of the thin wall are higher by approximately 40 MPa and 25 MPa than those of thick structure at room temperature and 200°C, respectively. The all elongations are reached above 2.0%, which do not contain specimens with casting defects.

(2) The main morphologies of the eutectic Si phases of the thin wall are spherical while those of the thick structure are rod-like, of which the grain size is smaller of thin wall. The finely and globularly eutectic Si phase can pin dislocations during testing, which is beneficial for tensile properties. Hence, the specimens of thin wall possess higher strength and elongation.

(3) A lot of fine and globular dimples are found in the fracture of the thin wall in ZL114A alloy component, while some cleavage platforms and casting defects exist in the thick structure. It also demonstrates that the elongation of the thin wall is better in comparison to the thick structure.

REFERENCES

[1] M. Qi, Y. Kang, Q. Qiu, W. Tang, J. Li, Microstructures, mechanical properties, andcorrosion behavior of novel high-thermal-conductivity hypoeutectic Al-Si alloys prepared by rheological high pressure die-casting and high pressure die-casting, J. Alloys Compd. **15** (745), 487-502 (2018).

[2] V. Dao, S. Zhao, W. Lin, C. Zhang,Effect of process parameters on microstructure and mechanical properties in AlSi9Mg connecting-rod fabricated by semi-solid squeeze casting, Mater. Sci. Eng. A **558**, 95-102 (2012).

[3] H.J. Kang, P.H. Yoon, G.H. Lee, J.Y. Park, B.J. Jung, J.Y. Lee, C.U. Lee, E.S. Kim, Y. S. Choi, Evaluation of the gas porosity and mechanical properties of vacuum assisted pore-free die-cast Al-Si-Cu alloy, Vacuum **184**, 109917 (2020).

[4] X. Wang, M. Guo, L. Cao, J. Luo, J. Zhang, L. Zhuang, Effect of heating rate on mechanical property, microstructure and texture evolution of Al-Mg-Si-Cu alloy during solution treatment, Mater. Sci. Eng. A **621**, 8-17 (2015).

[5] L. Zuo, B. Ye, J. Feng, Q. Bao, X. Kong, H. Jiang, W. Ding, Phases formation and evolution at elevated temperatures of Al-12Si-3. 8Cu-2Ni-1Mg alloy, Adv. Eng. Mater. **19** (3), 1600623 (2016).

[6] X. Li, S.M. Xiong, Z. Guo, Correlation between porosity and fracture mechanism in high pressure die casting of AM60B alloy, J. Mater. Sci. Technol. **32** (1), 54-61 (2016).

[7] Z. Yuan, Z. Guo, S.M. Xiong, Effect of as-cast microstructure heterogeneity on aging behavior of a high-pressure die-cast A380 alloy, Mater. Char. **135**, 278-286 (2018).

[8] H.X. Cao, Q.C. Sun, Q.Q. Pu, L.H. Wang, M.T. Huang, Z.W. Luo, J.Q. Che, Effect of vacuum degree and T6 treatment on the microstructure and mechanical properties of Al-Si-Cu alloy die castings, Vacuum **172**, 109063 (2020).

[9] R.X. Liu, J. Zheng, L. Godlewski, J. Zindel, M. Li, W.K. Li, S.Y. Huang, Infuence of pore characteristics and eutectic particles on the tensile properties of Al-Si-Mn-Mg high pressure die casting alloy, Mater. Sci. Eng. **A 7**, 13928083 (2020).

[10] X.G. Dong, J. Zhou, Y.J. Jia, B. Liu, Effect of alloying on high temperature fatigue performance of ZL114A (Al-7Si) alloy, Trans. Nonferrous Met. Soc. China **22**, 661-667 (2012).

[11] L.T. Jiang, G.H. Wu, W.S. Yang, Y.G. Zhao, S.S. Liu, Effect of heat treatment on microstructure and dimensional stability of ZL114A aluminum alloy, Trans. Nonferrous Met. Soc. China **20**, 2124-2128 (2010).

[12] H.J. Kang, H.S. Jang, S.H. Oh, P.H. Yoon, G.H. Lee, J.Y. Park, E.S. Kim, Y.S. Choi, Effects of solution treatment temperature and time on the porosities and mechanical properties of vacuum die-casted and T6 heat-treated Al-Si-Mg alloy, Vacuum **193**, 110536 (2021).

[13] R.S. Bonatti, Y.A. Meyer, A.D. Bortolozo, D. Costa, W.R. Osorio, Morphology and size effects on densification and mechanical behavior of sintered powders from Al-Si and Al-Cu casting alloys, J. Alloys Compd. **786**, 717-732 (2019).

[14] J.F. Hao, BY. Yu, J.C. Bian, L. Zheng, S.N. Nie, R.X. Li, Comparison of the semisolid squeeze casting and gravity casting process on the precipitation behavior and mechanical properties of the Al-Si-Cu-Mg alloy, Mater. Charact. **180**, 111404 (2021).

[15] G. Urrutia, M.A. Muñoz-Morris, D.G. Morris, Contribution of microstructural parameters to strengthening in an ultrafne-grained Al-7% Si alloy processed by severe deformation, Acta Mater. **55**, 1319-1330. (2007)

[16] Z. Zribi, H.H. Ktari, F. Herbst, V. Optasanub, N. Njah, EBSD, XRD and SRS characterization of a casting Al-7wt%Si alloy processed by equal channel angular extrusion: Dislocation density evaluation, Mater. Charact. **153**, 190-198 (2019).

[17] S. Shivkumar, S. Ricci, C. Keller, D. Apelian, Effect of solution treatment parameters on tensile properties of cast aluminum alloys, J. Heat Treat. **8**, 63-70 (1990).

[18] D.L. Zhang, L.H. Zheng, D.H. StJohn, Effect of a short solution treatment time on microstructure and mechanical properties of modifed Al-7wt.%Si-0.3wt.%Mg Alloy, J. Light Met. **2**, 27-36 (2002).