Modeling of Processing-microstructure-properties(PMP) Relationships of 2195 Al-Li Alloy for Cyro-deformation and Heat Treatment Based on Data-driven Approach

Huabo Zhou[1,2,a], Wei Liu[1,2] and Shijian Yuan[1,2]

[1]School of Material Science and Engineering, Harbin Institute of Technology, Harbin 150001, China,

[2]National Key Laboratory for Precision Hot Forming, Harbin Institute of Technology, Harbin 150001,China

[a]huabozhou@outlook.com

Abstract

The third-generation Al-Li alloys, represented by 2195 Al-Li alloy, have great improvements in strength, modulus of elasticity, stiffness, fracture toughness and corrosion resistance compared to conventional Al alloys, and have excellent applications in aerospace lightweight structures [1, 2, 3]. Unfortunately, the addition of lithium to aluminium, in addition to the benefits it brings, also leads to a decrease in the elongation, formability and fracture toughness of Al-Li alloys [4]. Deformation and Heat Treatment are the main strengthening methods for Al-Li alloys. This is because the mechanical properties and fracture mode of Al-Li alloys are related to the dislocation density as well as the type, size, distribution and number density of precipitated phases. Pre-deformation increases the number density of nucleation sites and thus promotes the precipitation of the phases, as demonstrated by Xie et al [5]. In addition, Cheng et al. in their study of the deformation behaviour of Al-Cu-Mn alloys found that the elongation and hardening index were increased during cryo-deformation, and this phenomenon still exists in 2195 Al-Li alloys, which provides us with new ideas [6]. The matching of cryo-deformation and heat treatment techniques of Al alloys is less explored, based on which we try to regulate the heat treatment and cryo-deformation of 2195 Al-Li alloy in order to obtain a good matching of strength and plasticity, and thus to obtain a component with good service properties.

In this research, we systematically investigated the regulatory mechanism of the synergistic effect of cryogenic pre-deformation and heat treatment process on the mechanical properties and microstructure of 2195 Al-Li alloy. It was found that the UTS and yield strength gradually increased with the decrease of the deformation temperature, and when the deformation temperature was reduced from 25℃ to -196℃, the UTS increased from 581 MPa to 602 MPa, which was a 3.6% increase, and the yield strength increased from 538 MPa to 580 MPa, which was a 7.81% increase. At the same time, the elongation showed a trend of decreasing and then increasing, when the temperature was decreased from 25℃ to -70℃, the elongation showed a significant decrease from 7.50% to 6.35%, when the temperature continued to decrease to -130℃, the elongation increased back to be comparable with the room temperature, and the elongation increased to 8.55% when the temperature was further decreased to -196℃, which is a 14% increase from the room temperature. A process-property prediction model was established by designing 90 sets of process parameter combinations (predeformation amount, aging temperature, aging time) and combining with machine learning methods (KNN, SVM, LR, DT and MLP). The results show that SVM is the most accurate in predicting the UTS and yield strength: the accuracy of UTS prediction is 98.3880%, with a standard deviation of 0.4588%, and the accuracy of yield strength prediction is 96.7720%, with a standard deviation of 0.8981%. MLP was the most accurate in predicting elongation with an accuracy of 91.4680% and a standard deviation of 0.7872%. The elongation has more influencing factors than the UTS and yield strength, so the prediction accuracy is slightly lower than the other two, but still within the acceptable range. Convolutional neural network (CNN) was further used to analyse transmission electron microscopy (TEM) images to quantify the contribution of morphological features (average size, volume fraction) of precipitated phases, such as T1, δ‘ phase and θ’phases, to the strengths, and to simulate the evolution of the microstructures with the help of generative adversarial network (GAN) under different processes. It is shown that the pre-deformation promotes the nucleation of precipitated phases through the introduction of dislocations, while the nonlinear coupling of aging parameters significantly affects the mechanical properties, which provides a theoretical basis and methodological framework for the optimisation of strength-plasticity matching.

Keywords

2195 Al-Li Alloy, Cryo-deformation, Heat Treatment, Machine Learning, Microstructure Characterization, Strength-plasticity Synergism

Possible Sessions

6. Data Driven Testing, 13. Metals and Microstructure.

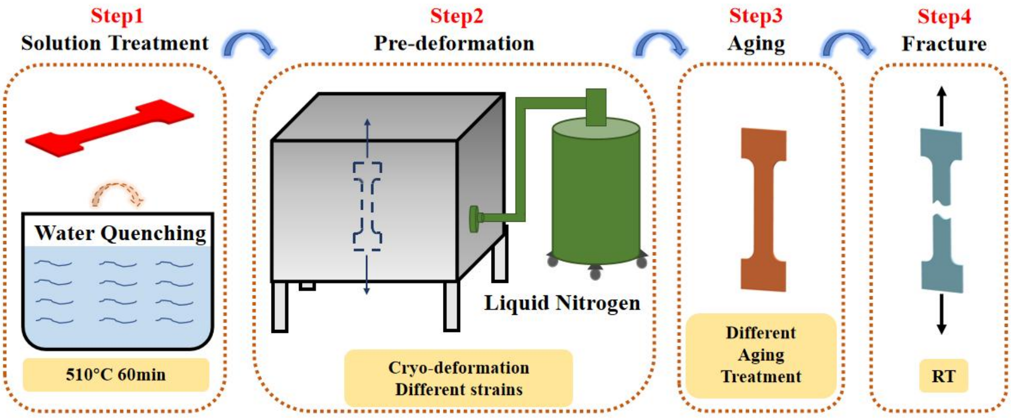

Fig. 1 Cryo-deformation and heat treatment process diagram.

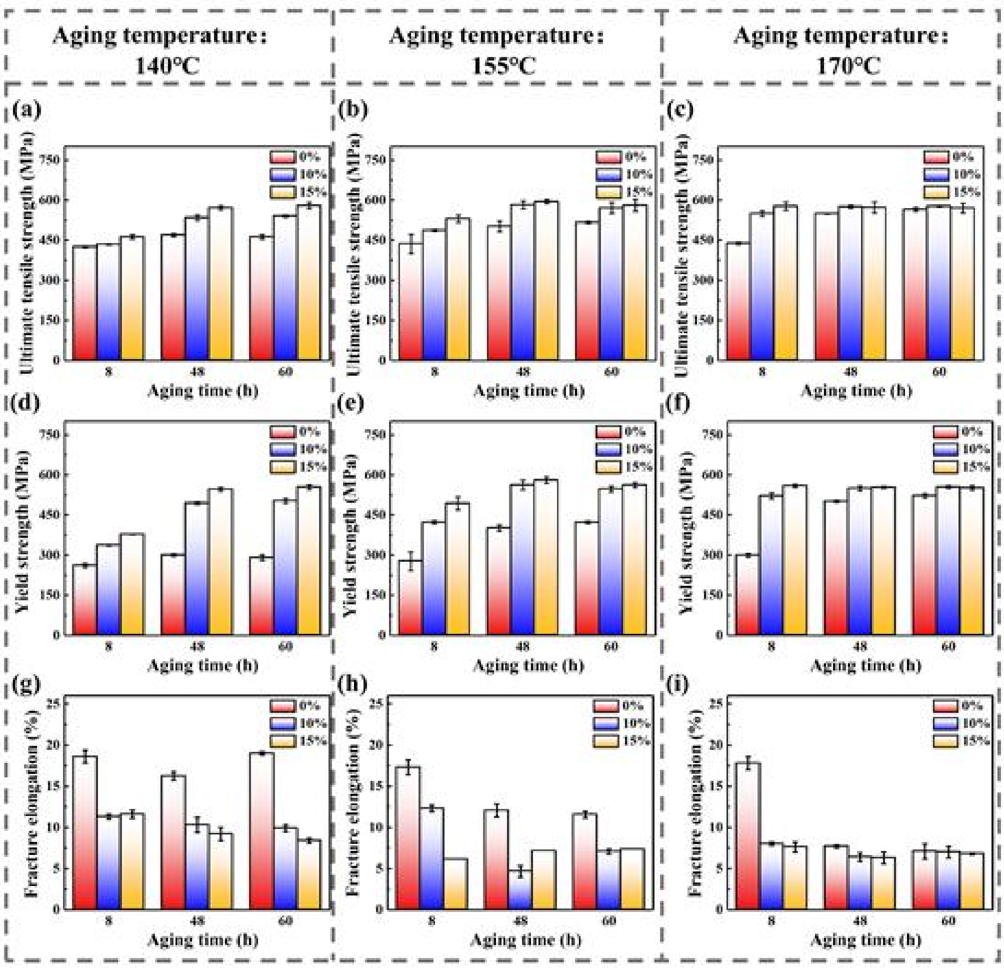

Fig. 2 Mechanical properties of partial specimens.

References

[1] A. Abd El-Aty, Y. Xu, S.H. Zhang, Y. Ma, D.Y. Chen:*Experimental investigation of tensile properties and anisotropy of 1420, 8090 and 2060 Al-Li alloys sheet undergoing different strain rates and fibre orientation: a comparative study*, Procedia Eng, Vol. 207 (2017), p 13-18.

[2] S. Betsofen, V. Antipov, M. Knyazev:*Al–Cu–Li and Al–Mg–Li alloys: phase composition, texture, and anisotropy of mechanical properties (Review),* Russ Metall, Vol 4 (2016), p 326-341.

[3] J.F. LI, H.R. LI, Z.A. Wang:*Correlations between Properties and Structures of Al-Li Alloys and Novel Alloy Design*, Materials China, Vol. 41 (2022), p 796-807.

[4] E. Lavernia, T. Srivatsan, F. Mohamed:*Strength, deformation, fracture behaviour and ductility of aluminium-lithium alloys,* J Mater Sci, Vol. 25 (1990), p 1137-1158.

[5] B.X. Xie, L. Huang, J.H. Xu, H.L. Su, H.P. Zhang, Y.K. Xu, J.J. Li, Y. Wang:*Effect of the aging process and pre-deformation on the precipitated phase and mechanical properties of 2195 Al–Li alloy*, Mater. Sci. Eng., A, Vol. 832 (2022), p 142394.

[6] W.J. Cheng, W. Liu, S.J. Yuan:*Deformation behavior of Al–Cu–Mn alloy sheets under biaxial stress at cryogenic temperatures*, Mater. Sci. Eng., A, Vol.759 (2019), p 357-367.