GU J Sci, Part C,10(2): 195-202 (2022)

Gazi University

Journal of Science

PART C: DESIGN AND TECHNOLOGY

http://dergipark.gov.tr/gujsc

Enhancement of impact toughness properties of Al 7075 alloy via double aging heat treatment

Onur ALTUNTAŞ[1*]

[1] National Defense University, Alparslan Defense Sciences and National Security Institute, Department of Warfare Weapons and Tools, Ankara, Türkiye

Article Info

Research article
Received:23/042022
Revision:28/04/2022
Accepted:19/05/2022

Keywords

Al 7075
double aging
microstructure
XRD analysis
impact toughness

Abstract

In this study, Charpy impact test specimens were prepared by cutting Al 7075 alloy according to ASTM-E23 standards. The prepared test specimens were dissolved in a single-phase region for 1 hour at 480°C in vacuum atmosphere and artificially aged at 120°C for 24 hours after quenching. After the first step aging heat treatment applied, the specimens were artificially aged for 5-50 hours at 180°C for the second time. Microstructural characterization and fracture surface analyzes of the specimens were determined using SEM (Scanning Electron Microscope) device, crystallographic analysis of the precipitated phases were determined using XRD (X-ray diffraction) device. The increase in the amount of η1 phase (MgZn2) with increasing double aging heat treatment time was effective in increasing the strength. After 10 hours of double aging heat treatment, the impact toughness value is improved by 300% compared to the single aged condition.

1. INTRODUCTION

7XXX series (Al-Zn-Mg-Cu) aluminum alloys are widely used in automobile, aerospace and defense industries due to their low density, easy formability, high mechanical and corrosive resistance [1-3]. With the increase in global fuel prices, the advantage of using aluminum alloys in vehicles comes to the fore. It has been stated that by reducing the weight of land vehicles by 10%, fuel efficiency can be increased by 5% and greenhouse gas emissions can be significantly reduced. In addition, increasing the range of electric vehicles by reducing the weight of the automobile is an important financial indicator [4,5]. Microstructure, corrosive and mechanical properties of aluminum alloys can be improved by applying aging heat treatments with different cycles, thermo-mechanical methods and retrogression and re-aging (RRA) heat treatment processes [6-10]. Sequence of precipitation of artificially aged 7000 series aluminum alloys;

Solid solution (SS) → GP zones → η^{1} → $\eta(MgZn_2)$

It has been reported that GP regions [11,12] and metastable η' ($MgZn_2$) precipitates [13,14] are effective in the increase in strength of the alloy as a result of aging heat treatment. In the study by Y. Fan et al. [15] in which the effects of single and two-stage aging processes applied to Al 7075 alloy on age hardening and precipitation behavior were compared, it was reported that the hardness was 184 HV after single aging, 182 HV after double aging, and mechanical properties gave similar results. In a study by Cai, SW et al. [16] investigating the effects of single and double aging heat treatment applied to Al 7075 alloy on strength, in double aging heat treatment the hardness of the alloy is double peak and the strengthening stage of the first peak aging state is mainly high density GP regions. , and the strengthening phase of the second peak aging state was reported to be the η'($MgZn_2$) phases.

Many studies [17-20] have been carried out on the thermodynamic and crystallographic formation processes of the precipitations of Al7075 alloy formed as a result of aging heat treatment, and in this study, the effects of double aging at different times on microstructural and crystallographic properties and impact toughness will be examined.

*Corresponding author, e-mail: oaltuntas@kho.msu.edu.tr
DOI: 10.29109/gujsc.1108116

2.MATERIALS AND METHODS

Commercially purchased 10 mm thick Al 7075 sheet was used in the experimental studies. V-notched impact test specimens conforming to ASTM-E23 standard were cut with the help of Mitsubishi MV1200S CNC Wire Erosion cutting device and made ready for heat treatment. The chemical composition of the Al 7075 alloy used as the starting specimen was determined with a spectrometer (Q4 TASMAN) and presented in Table 1.

Table 1. *Chemical composition of Al 7075 alloy (% by weight)*

	wt (*%*)								
Standart	Fe	Si	Mn	Cr	Ti	Cu	Mg	Zn	Al
(*TS-EN 573-3*)	0,12	0,07	0,03	0,19	0,05	1,6	2,7	5,8	Balance

.

The dissolution of the specimens in the single-phase region and the subsequent artificial aging heat treatments were carried out in a $5x10^{-2}$ Pa vacuum atmosphere in a chamber type horizontal high temperature furnace. After solid solution heat treatment the specimens for 1 hour at 480°C, they were rapidly cooled in cold water to form a supersaturated solid solution structure and then artificially aged at 120°C for 24 hours. These single-aged serial specimens were coded as FA. Some FA specimens were re-aged a second time for 5-50 hours at 180°C and were coded as DA5-DA50, respectively. The schematic representation of the heat treatments applied to the specimens is given in Figure 1.

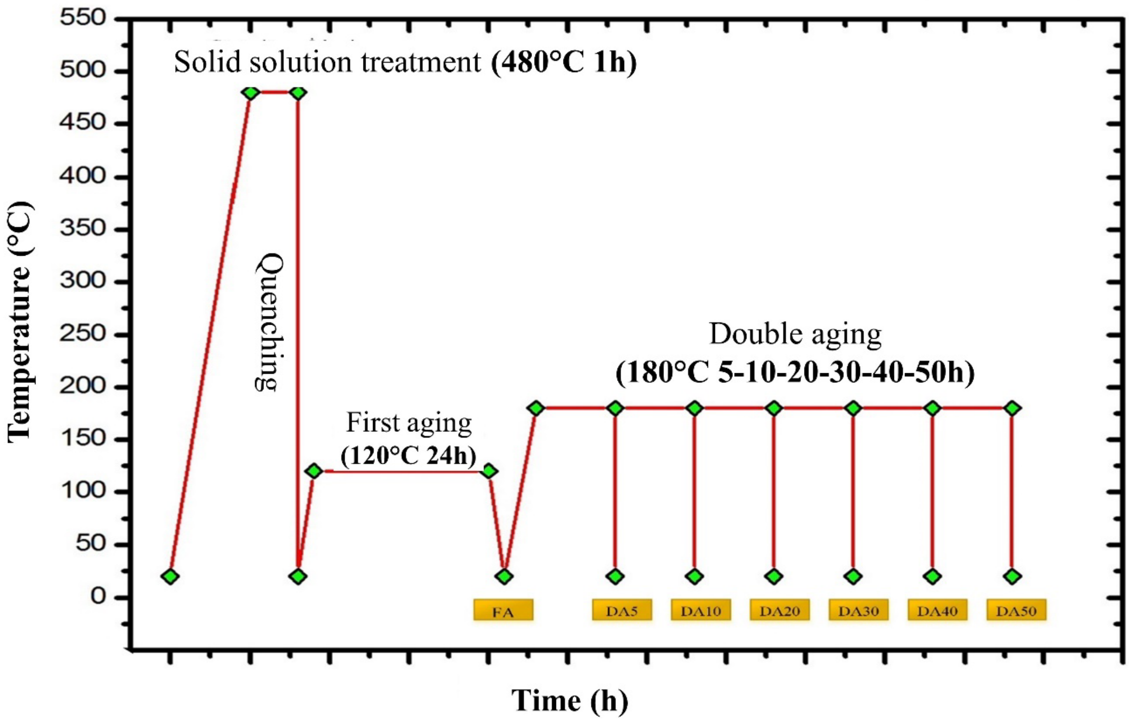

Figure 1. *Schematic representation of the double aging heat treatment applied to the specimens*

The HV1 Vickers macro hardness values of the specimens were determined using 1 kg (9,807N) indenter for 15s and according to the ASTM E384 with HMV-2 Shimadzu Hardness tester. The tests of V-notched Charpy impact specimens prepared according to ASTM E23 standard were carried out at room temperature in an Instron –Wolpert brand impact tester with 300 J hammer capacity. Microstructure and fracture surface analyzes were performed using the JEOL JSM-6060LV Scanning Electron Microscope (SEM). For microstructure studies, all specimens were etched with Keller solution (95% H_2O, 1.5% HCl, 1% HF and 2.5% HNO_3) after conventional metallography processes. After heat treatment detection of Al and $MgZn_2$

precipitated and the other possible phases were made with Bruker D8 Advanced X-ray device using CuKα (λ=0.154 nm) target and step size 0.06 °/s..

3.RESULTS

In Figure 2a, the SEM microstructure image of the FA specimen, which was treated with conventional aging heat treatment in single step, is given. It is seen that the grains due to rolling are oriented in the microstructure. Spheroidal precipitates (in circles) with an average diameter of 9µm in the Al matrix are thought to be metastable η₁ phases [21]. In the studies [22,23], it is supported that the very small size (<4nm) precipitates indicated by the red arrow are GP regions.

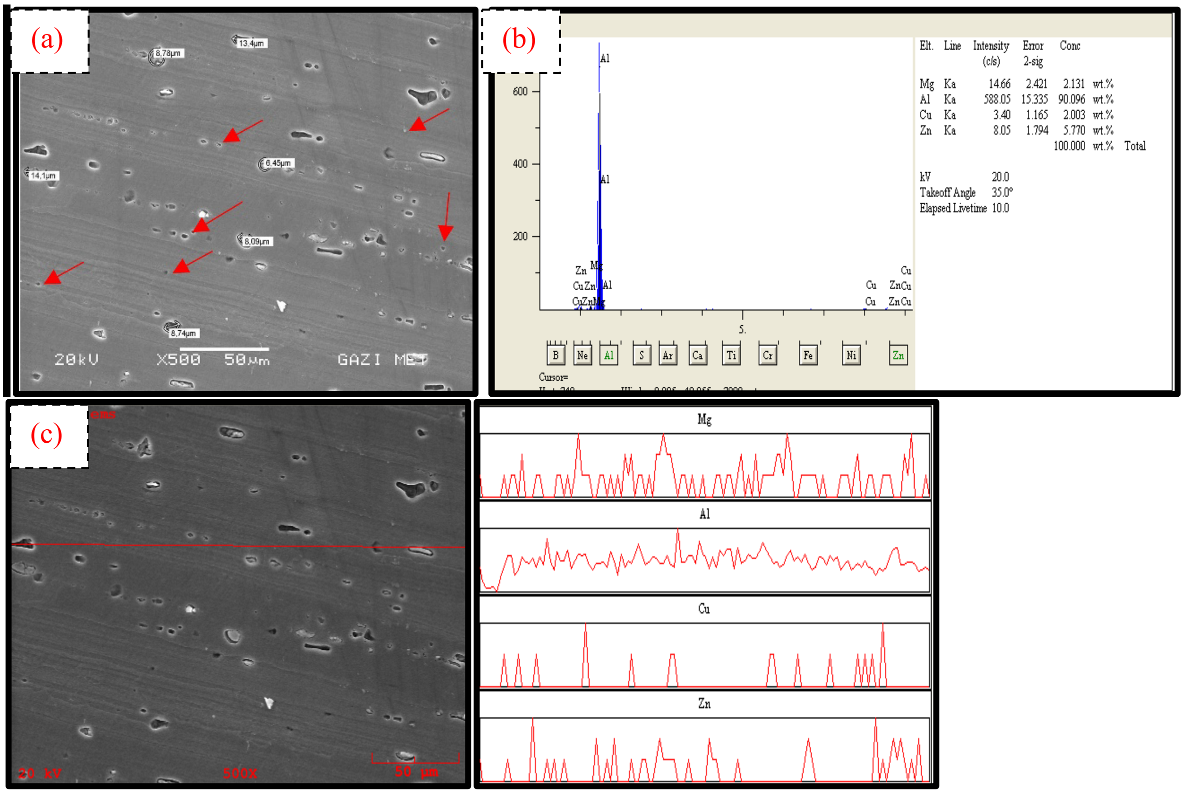

Figure 2. *Microstructure images of the FA specimen (a) SEM, (b) General EDS and (c) Linear EDS*

The precipitates characterization performed on both conventional single aged and double aged specimens at different times shows several disc-like stable precipitates and a large amount of fine precipitate in both of these two specimens. It was also observed that the precipitates grew with increasing second aging time. This can be explained by the Ostwald ripening, which has a more stable thermodynamic structure and small particles disappear [24,25]. As a result of coalescence and Ostwald ripening, spherical precipitates appear in the microstructures with some increase in average grain size (Fig.3d-f).

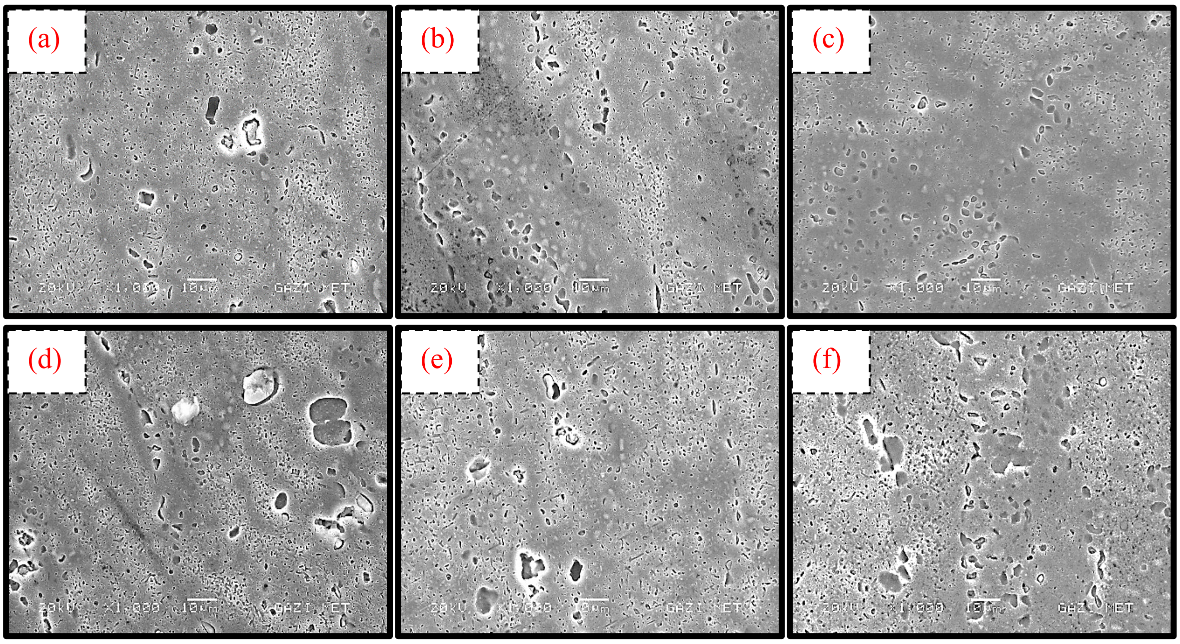

Figure 3. *SEM microstructure images of specimens double aged at different times; (a) DA5, (b) DA10, (c)DA20, (d) DA30, (e) DA40, (f) DA50*

In Figure 4, the impact toughness and hardness values of all specimens are presented together graphically. The impact toughness value of the DA10 specimen increased by approximately 300% compared to the initial specimen (FA). It is observed that the hardness and impact toughness increase together in the double aging heat treatment process up to 10 hours. The highest hardness and impact toughness were determined as 178 HV1 and 31 $J.cm^{-2}$ respectively in the DA10 specimen. It is thought that this situation is caused by the GP and η' phases, which precipitated in large amounts in the matrix. Although the hardness values of DA20-DA50 specimens decreased significantly the impact toughness values decreased relatively. This situation is thought to be caused by the η phases, which are abundant in the matrix due to over aging.

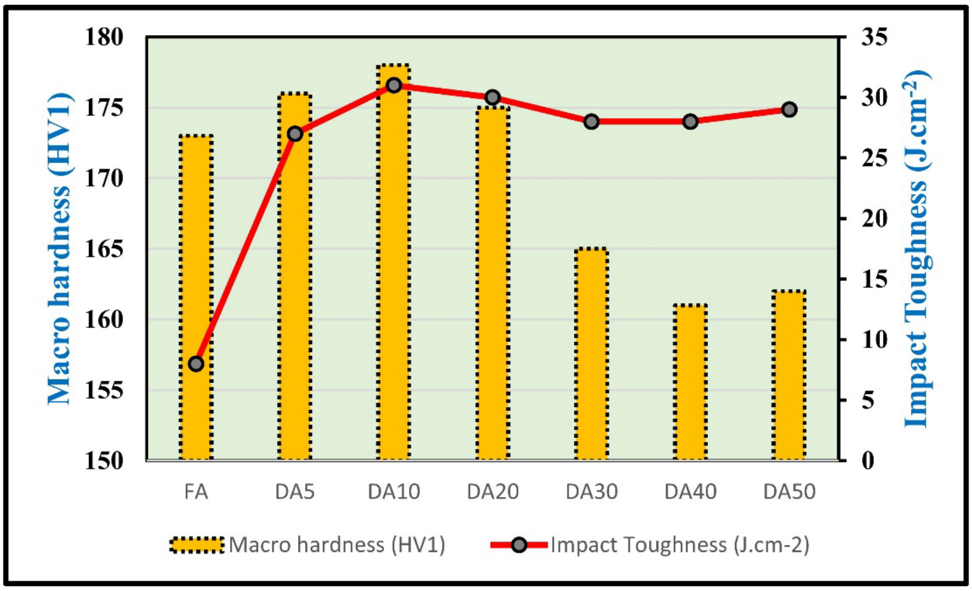

Figure 4. *The graph of macro hardness (HV1) and impact toughness ($J.cm^{-2}$) values of the specimens*

Figure 5 illustrates the SEM fractograph of all specimens. In Fig.5a, in the fracture surface photograph of the FA specimen, there are very dense cleavage separations as well as a small amount of dimples. This is the most important indicator of brittle fractures due to low impact toughness. In figure 5(b-f), the fracture morphologies of the DA5-DA50 specimens which were second aged are presented respectively. The presence of very intense dipmles is striking in all double-aged specimens. It shows that high impact toughness and ductile fracture are provided together. It is also observed that the dimples become larger with increasing double aging time. It is thought that the strength increases with the increase of the secondary phase particles formed in the depressions of the fracture surfaces [26,27].

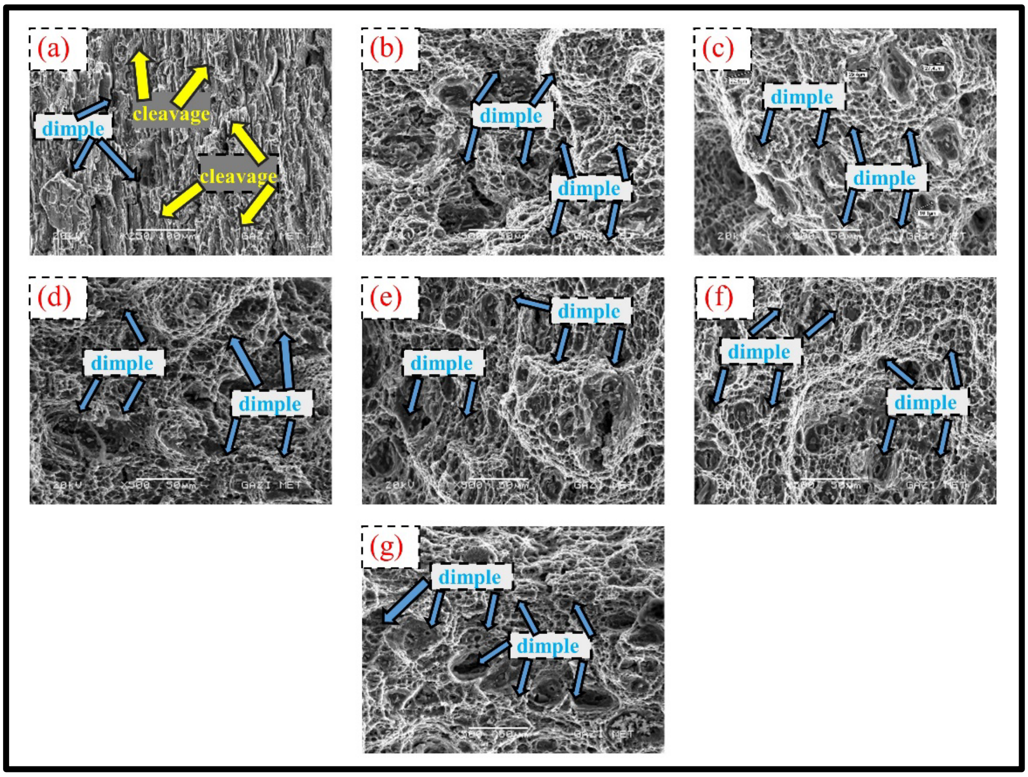

Figure 5. *Fracture surface morphology of the (a) FA, (b) DA5, (c) DA10, (d) DA20, (e) DA30, (f) DA40, (g) DA50 specimens.*

In Figure 6, the XRD results of the specimens are presented. In the XRD graph the main Al peaks in (111), (200), (220) and (311) planes respectively and $MgZn_2$ peaks in the form of noise are seen in all heat treatment series. This supports that the microstructure is formed by α-Al and $MgZn_2$ precipitates [28]. As a result of different heat treatment and thermo-mechanical treatments applied to the specimens the intensity and widths of the peaks can change [29,30]. As a result of the double aging process, the peak intensity of the (111) plane at 38° decreased compared to the FA specimen while all other Al peaks intensities are increased significantly.

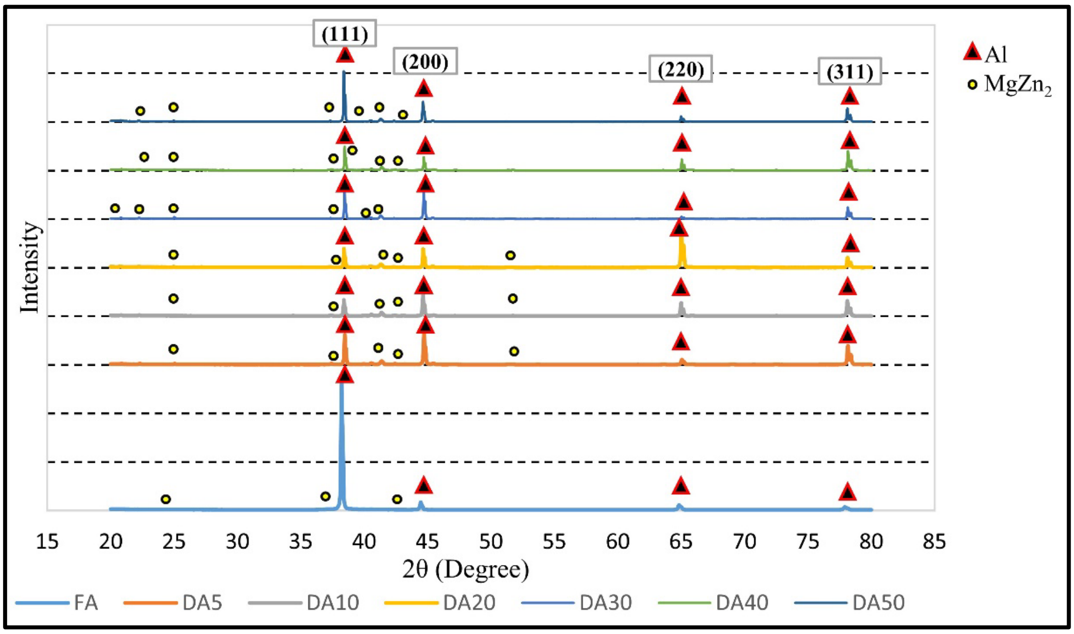

Figure 6. *XRD patterns for all of specimens.*

4.CONCLUSIONS

The following results were obtained for the Al 7075 alloy, which was subjected to double aging heat treatment at different times.

1- The highest hardness and impact toughness values were determined as 178 HV1 and 31 $J.cm^{-2}$ in the DA10 specimen respectively.

2- An increase was observed in the precipitated $MgZn_2$ phases depending on the increasing secondary heat treatment time.

3- It was determined by the mechanical properties that the samples exhibited over aging properties with secondary aging of 20 hours and above.

4- The impact toughness value of the DA10 specimen has been improved by approximately 300% compared to the inital specimen (FA).

ACKNOWLEDGEMENTS

This study has been financially supported by the Gazi University Scientific Research Projects Coordination Unit [under Project Number FGA-2021-7002].

.

REFERENCES

[1] Han, N. M., et al. "Effect of solution treatment on the strength and fracture toughness of aluminum alloy 7050." *Journal of Alloys and Compounds* 509.10 (2011): 4138-4145.

[2] Altuntaş, Gözde, and Bülent Bostan. "Al–Zn–Mg–Cu Alaşımının Kristalografisine RRA Isıl İşlemi Etkilerinin İncelenmesi." *Politeknik Dergisi*: 1-1.

[3] Mondolfo, Lucio F. Aluminum alloys: structure and properties. *Elsevier*, 2013.

[4] Karakoyun, F., D. Kiritsis, and K. Martinsen. "Holistic life cycle approach for lightweight automotive components." *Metallurgical Research & Technology* 111.3 (2014): 137-146.

[5] Ma, Wenyu, et al. "Influence of solution heat treatment on mechanical response and fracture behaviour of aluminium alloy sheets: an experimental study." *Materials & Design* 88 (2015): 1119-1126.

[6] Ozer, A.,"The microstructures and mechanical properties of Al-15Si-2.5 Cu-0.5 Mg/(wt%) B_4C composites produced through hot pressing technique and subjected to hot extrusion, *Materials Chemistry and Physics,* 183, 288-296. (2016).

[7] Srinivasan, Nedunchezhian, et al. "The role of brass texture on the deformation response of 7075-T651 aluminum alloy under equi-biaxial tension." *Materials Science and Engineering: A* 812 (2021): 141133.

[8] Aksöz, S., & Bostan, B., "Effects of ageing and cryoageing treatments on microstructure and hardness properties of AA2014–SiC MMCs" *Transactions of the Indian Institute of Metals*, 71(8), 2035-2042, (2018).

[9] Altuntaş, Gözde, Onur Altuntaş, and Bülent Bostan. "Characterization of Al-7075/T651 Alloy by RRA Heat Treatment and Different Pre-deformation Effects." Transactions of the Indian Institute of Metals 74.12 (2021): 3025-3033.

[10] Kaplan, Yavuz, et al. "The effect of aging processes on tribo-metallurgy properties of Al based ternary Alloys product by P/M technique." *Science of Sintering* 52.4 (2020).

[11] Berg, L. K., et al. "GP-zones in Al–Zn–Mg alloys and their role in artificial aging." *Acta Materialia* 49.17 (2001): 3443-3451.

[12] Song, R. G., and Q. Z. Zhang. "Heat Treatment Optimization For 7175 Aluminum Alloy By Genetic Algorithm." *Materials Science and Engineering: C* 17.1-2 (2001): 133-137.

[13] Liu, J. Z., et al. "Revisiting The Precipitation Sequence İn Al–Zn–Mg-Based Alloys By High-Resolution Transmission Electron Microscopy." *Scripta Materialia* 63.11 (2010): 1061-1064.

[14] Zhou, Pu, et al. "Mechanical Behavior And Deformation Mechanism Of 7075 Aluminum Alloy Under Solution İnduced Dynamic Strain Aging." *Materials Science and Engineering: A* 759 (2019): 498-505.

[15] Fan, Yun, et al. "Comparisons of Age Hardening and Precipitation Behavior in 7075 Alloy Under Single and Double-Stage Aging Treatments." *Metals and Materials International* 27.10 (2021): 4204-4215.

[16] Cai, S. W., Y. He, and R. G. Song. "Study on the Strengthening Mechanism of Two-Stage Double-Peaks Aging in 7075 Aluminum Alloy." *Transactions of the Indian Institute of Metals* 73.1 (2020): 109-117.

[17] Emani, S. V., et al. "Double aging and thermomechanical heat treatment of AA7075 aluminum alloy extrusions." *Journal of materials science* 44.23 (2009): 6384-6391.

[18] Kverneland, A., et al. "Transformations and structures in the Al–Zn–Mg alloy system: A diffraction study using synchrotron radiation and electron precession." *Materials Science and Engineering: A* 528.3 (2011): 880-887.

[19] Lechner, Wolfgang, et al. "Microstructure and vacancy-type defects in high-pressure torsion deformed Al–Cu–Mg–Mn alloy." *Scripta materialia* 61.4 (2009): 383-386.

[20] Dai, Pan, et al. "Nano-scale precipitate evolution and mechanical properties of 7085 aluminum alloy during thermal exposure." *Materials Science and Engineering: A* 729 (2018): 411-422.

[21] Harkness, S. D., and J. J. Hren. "An investigation of strengthening by spherical coherent GP Zones." *Metallurgical Transactions* 1.1 (1970): 43-49.

[22] Osamura, K., et al. "Structure of GP zones in an Al-1.7 at.% Cu alloy aged for 14 years at room temperature." *Acta Metallurgica* 31.10 (1983): 1669-1673.

[23] Liu, Siliang, et al. "On the atomic model of Guinier-Preston zones in Al-Mg-Si-Cu alloys." *Journal of Alloys and Compounds* 745 (2018): 644-650.

[24] Jiang, Jufu, et al. "Comparison of microstructural evolution of 7075 aluminum alloy fabricated by SIMA and RAP." *Journal of Materials Processing Technology* 238 (2016): 361-372.

[25] Fu, Jin-Long, Hong-Jun Jiang, and Kai-Kun Wang. "Influence of processing parameters on microstructural evolution and tensile properties for 7075 Al alloy prepared by an ECAP-based SIMA process." *Acta Metallurgica Sinica (English Letters)* 31.4 (2018): 337-350.

[26] Higgins R A, The Properties of Engineering Materials, Industrial Press Inc. (1994).

[27] Putra, Ichsan S., and Jaap Schijve. "Crack opening stress measurements of surface cracks in 7075-T6 aluminium alloy plate specimen through electron fractography." *Fatigue & Fracture of Engineering Materials & Structures* 15.4 (1992): 323-338.

[28] Mo, Taiqian, et al. "Enhancing of mechanical properties of rolled 1100/7075 Al alloys laminated metal composite by thermomechanical treatments." *Materials Science and Engineering: A* 800 (2021): 140313.

[29] Krishna, N. Naga, et al. "Mechanical anisotropy and microstructural changes during cryorolling of Al–Mg–Si alloy." *Materials Characterization* 107 (2015): 302-308.

[30] Liu, Yan, et al. "Heating aging behavior of Al–8.35 Zn–2.5 Mg–2.25 Cu alloy." *Materials & Design* 60 (2014): 116-124.