International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:8, No:3, 2014

Aging and Mechanical Behavior of Be-Treated 7075 Aluminum Alloys

Mahmoud M. Tash, S. Alkahtani

***Abstract*—The present study was undertaken to investigate the effect of pre-aging and aging parameters (time and temperature) on the mechanical properties of Al-Mg-Zn (7075) alloys. Ultimate tensile strength, 0.5% offset yield strength and % elongation measurements were carried out on specimens prepared from cast and heat treated 7075 alloys. Aging treatments were carried out for the as solution treated (SHT) specimens (after quenching in warm water). The specimens were aged at different conditions; Natural aging was carried out at room temperature for different periods of time. Double aging was performed for SHT conditions (pre-aged at different time and temperature followed by high temperature aging). Ultimate tensile strength, yield strength and % elongation as a function of different pre-aging and aging parameters are analyzed to acquire an understanding of the effects of these variables and their interactions on the mechanical properties of Be-treated 7075 alloys.

***Keywords*—Duplex Aging Treatment, Mechanical Properties, Al-Mg-Zn (7075) alloys.

I. Introduction

THE design of aerospace aluminum alloys is mainly rooted in optimizing the strength and ductility, both of which can be enhanced by controlling the added alloying elements as well as the heat treatment conditions. In Al/Zn/Mg, alloy it was found that storage at room temperature before heat to the aging temperature leads to the formation of finer precipitate structure and better properties. Duplex aging enhances corrosion resistance since the grain boundary zone is removed. The 7075 alloy also demonstrates a high response to age hardening [1]-[3]. Aging at 120°C for 24hs was recommended for 7075 alloys [2]-[4]. Using a combination of T6 (120°C/24hs) and T73 tempers was recommended to resist stress corrosion cracking; also, increasing the Cu content compensates for the over-aging effect in strength reduction [2], [4]. Retrogression and reaging (RRA) are expected to optimize the 7000 alloy series tensile properties. The RRA sequence after solution heat treatment and quenching in cold water is: i) T6 aging, 120°C/24h, ii) short time heating, 200-250°C/5-10min, followed by cold water quenching and iii) T6 re-aging, 120°C/24h [5], [6]. Many studies [7]-[12] focused on the effect of heat treatment on 7075 alloys. Increases in the strength of the 7075 alloy are believed to arise mainly from of the fine dispersion of small ή particles [9]. The microstructure of the grain boundary particles which depend on the aging process is the main parameter controlling the 7075 alloy mechanical properties. The high strength of this alloy in the RRA temper is considered to arise from both the presence of many fine ή particles, which are probably coherent, and of the high overall concentration of particles in this structure [11]. The purpose of this investigation is to study the influence of such heat treatment on the mechanical properties of the series 7xxx (Al-Mg-Zn) and particularly the alloys commercially known 7075. By study the impact of Be additions and heat treatments for Al-Mg-Zn (7075) aluminum alloys on the mechanical properties, it is possible to determine conditions necessary to achieve optimum mechanical properties.

S. Alkahtani is with Industrial Engineering Program, Mechanical Engineering Department, College of Engineering, Salman bin AbdulAziz University, Al Kharj, KSA (e-mail: salqahtany@hotmail.com).
M. Tash is with Industrial Engineering Program, Mechanical Engineering Department, College of Engineering, Salman bin AbdulAziz University, Al Kharj, KSA, on leave from the Mining, Petroleum and Metallurgical Engineering Department, Cairo University, Giza, Egypt (e-mail: mahmoud_tash1@yahoo.com).

II. Experimental Procedures and Methodology

Experimental 7075 alloy was prepared through the addition of measured amounts of Mg, Zn, Si, Cu, and Fe to the molten aluminum. Table I shows the average chemical composition of the base alloy investigated. Measured Mg, Zn, Si, Cu, Fe and other additions were made to the melt. Alloying elements were added in the form of master alloys or pure metals to obtain the pre-determined level/levels of each. Prior to casting, the molten metal were degassed for 15min using pure, dry argon to remove the hydrogen and inclusions. Several experimental alloys were prepared and tensile test bars were cast using an ASTM B-108 type permanent metallic mold that preheated to 450°C. Several sets of test bars corresponding to the base alloy were conventionally heat-treated, where the bars were, then quenched in 65°C warm water, followed by aging at different temperatures for different periods of time up to 100hr (see Table II). All samples will be solution heat-treated at 470ºC/8h, followed by warm water quenching (65°C).Tensile testing was carried out for the heat-treated test bars at room temperature using an MTS Servohydraulic mechanical testing machine working at a strain rate of 1.0×10-4/s. The elongation of the test specimens was measured using a strain gauge extensometer attached to the specimen during the tension test. For each sample tested a stress-strain curve was obtained to illustrate the mechanical behavior of each specimen under the applied load. A data acquisition system attached to the MTS machine provided the tensile test data, namely, elongation to fracture, yield strength at 0.2% offset strain and ultimate tensile strength. For each composition, five test bars were tested in the as-cast and heat-treated conditions. The microstructures of the polished sample surfaces were examined using an optical microscope linked to a Clemex image analysis system.

TABLE I
AVERAGE CHEMICAL COMPOSITION (WT %) OF THE BASE METAL AND THE 7075 ALLOYS (7B)

Code	Si	Fe	Mn	Mg	Cu	Zn	Cr	Ti	Sr	Zr	Be	Al
7B	0.19	0.4	0.325	2.15	2.02	6.47	0.287	0.013	0.012	0.001	0.024	Bal.

TABLE II
HEAT TREATMENT CONDITIONS FOR BE-CONTAINING 7075 ALLOYS

Conditions		Aging Heat treatment Description
1	As-cast	As-cast
2	SHT	SHT
3	T4	RT@ 24 h
4	T4	RT@ 96 h
5	T4	RT@ 192 h
6	DA1	Aging @ RT- 24 hr + Aging @180°C -8 hr
7	DA2	Aging @ 120°C -24 hr + Aging @180°C - 8 hr
8	DA3	Aging @ 65°C -24 hr + Aging @ 130°C -24 hr
9	DA4	Aging @ 110°C -8 hr + Aging @ 180°C -8 hr
10	RRA1	Aging @ 120°C -29 hr + Aging @200°C- 10 min.+ Aging @ 120°C -29 hr
11	RRA2	Aging @ 130°C -24 hr + Aging @175°C- 3hr. + Aging @ 130°C -24 hr

III. RESULTS AND DISCUSSIONS

A. Aging Behavior of Al-Mg-Zn Alloys (7075 Alloy)

The precipitation sequence of Al-Mg-Zn alloys is believed to be;

Supersaturated Solid Solution → G.P Zones → β''($MgZn_2$)→ ή'($MgZn_2$)→ η ($MgZn_2$) [3]

During the early stages of aging of an alloy of Al-Mg-Zn, the saturated solid solution first develops solute clusters. However, the supersaturation of vacancies allows diffusion, thus leading to zone formation, called GP zones. During natural aging (while the alloy is left at room temperature for a sufficiently long time), or aging below the G.P zone solvus line, G.P zones and η' are formed within the matrix. The hardening effect appears to be associated with a strong internal chemical effect, which makes them difficult to be cut by dislocations. The coherency, lattice distortion, and strain field around the G.P zones and η' particles restrict the dislocation motion, leading to an increase in the strength and hardness of the alloy. η' heterogeneously nucleated on dislocations if aging is carried out above the G.P zones solvus line. Fig. 1 shows the variation in alloy ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation for cast and heat treated 7075 Al-Mg-Zn alloy. Fig. 1 (a) shows the results for the as cast and SHT conditions. On the other hand the effect of pre-aging at RT, 65C, 120C and 110C with different time on the 8 hour aging at 180C are shown in Fig. 1 (c) where the duplex aging conditions.

Duplex aging is carried out in two steps: first at relatively low temperature below the G.P zones solvus, and then at a higher temperature. In this way a fine dispersion of G.P zones obtained during the first stage can act as heterogeneous nucleation sites for precipitation at the higher temperature. By this treatment, finer precipitate distributions were obtained than those obtained from the single ageing treatment at the higher temperature. Characteristic Feature of quenched and aged Al-Mg-Zn (7xxx) alloys is the presence of (PFZ) adjacent to the grain boundaries. Geisler [13] attributed the PFZ to preferential precipitation at the grain boundary and subsequent solute denudation in the region adjacent to the boundary prior to precipitation within the grains. A rapid quench followed by immediate aging would result in a coarse matrix precipitate distribution and a wide PFZ. However, the introduction of a short aging treatment at, say 100˚C between quenching and the higher temperature aging would refine the matrix precipitates and produce a narrow PFZ. This is called preaging or duplex aging. However, the interior of grains may develop an acceptable precipitate size and density. Duplex aging enhances corrosion resistance since the grain boundary zone is removed. The basic idea of all heat treatment is to seed a uniform distribution of stable nuclei at the low temperature which can then be grown to optimum size at the high temperature.

The double aging (DA) of 7075 alloy has positive effect on hardness, yield and ultimate tensile strengths. Moreover, double aging to peak hardness results in a significantly reduced processing time, which can lead to reduced energy and cost. The 7075 alloy also demonstrates a high response to age hardening. The results in Fig. 1 (c) show that as PA time (at room temperature and 120˚C) increases the 180˚C aging shows a remarkable level of strength, Fig. 1 (c). Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation is observed to have greater values when RRA is carried out at 120˚C and 130 for 24 and 29 hours, respectively, Fig. 1 (c).

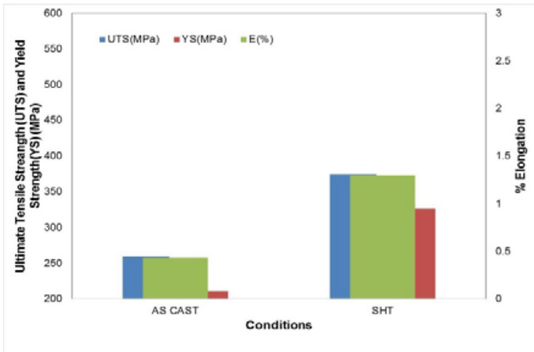

Fig. 1 (a) Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation for the as cast and SHT conditions

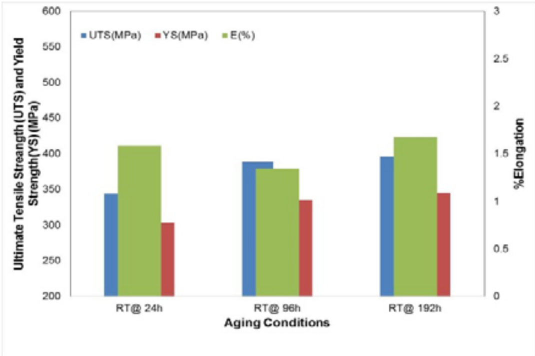

Fig. 1 (b) Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation for natural aging at different time (24, 96 and 192hr)

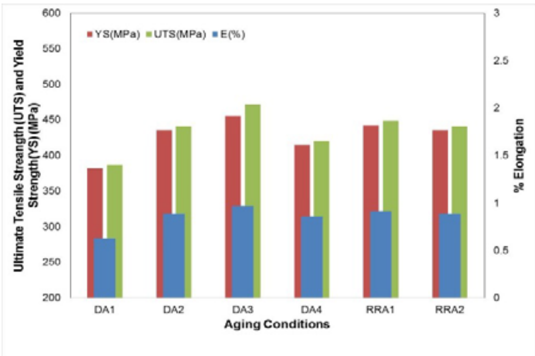

Fig. 1 (c) Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation for different conditions of duplex aging; DA1= aging @ RT- 24 hr + aging @180°C -8 hr; DA2= aging @ 120°C -24 hr + aging @180°C - 8 hr; DA3= aging @ 65°C -24 hr + aging @ 130°C -24 hr; DA4= aging @ 110°C -8 hr + aging @ 180°C -8 hr; RRA1= aging @ 120°C -29 hr + aging @200°C- 10 min.+ aging @ 120°C -29 hr; RRA2=aging @ 130°C -24 hr + aging @175°C- 3hr. + aging @ 130°C -24 hr

Fig. 1 Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation for as cast and SHT conditions (a), natural aging (b) with different time (24, 96 and 192hr) and duplex aging and/or pre-aging (c) at RT, 120C and 110C on 180C aging at 8h

B. Design of Experiment (DOE)

Statistical design of experiments (DOE) and fractional factorial design are efficient, well-established techniques which may be applied to study and control the properties and behavior of an alloy system, where, by developing regression equations between the response variable (mechanical properties) and the factor varied (pre-aging and aging heat treatment parameters, etc.), these equations may be used to predict the alloy processing/heat treatment conditions required to achieve the desired properties. Experimental correlations of the ultimate tensile strength, 0.5% offset yield strength and % elongation results were analyzed using factorial analysis method. Ultimate tensile strength, 0.5% offset yield strength and % elongation measurements were performed on all cast and heat-treated specimens prepared from the various 7075 alloys. Experimental correlations of the results obtained from the hardness measurements are analyzed through empirical models to establish the relations between the ultimate tensile strength, 0.5% offset yield strength and % elongation and different pre-aging and aging parameters of 7075 alloys. The main factors are Pre-aging Temperature (PA T^0C), Pre-aging time (PA t h), Aging temperature (AT^0C), Aging time (At h). Once the responses, factors (6) and levels have been selected, see Table III, the next step is to design the experimental runs. After the parameters and the values input into the software (MINITAB 14), a DOE model will be automatically generated with specific number of runs coupled with specific parametric settings. In this case, 50 runs were generated.

TABLE III
DESIGN OF EXPERIMENT (DOE)- FACTORS AND THEIR UNCODED LEVELS

No.	Parameters	Notation	Unit	Level			
				Uncoded		Coded	
				Low	High	Low	High
1	PA T 0C	A	0C	0	130	-1	1
2	PA t h	B	H	0	29 h	-1	1
3	AT1 0C	C	0C	0	200	-1	1
4	At1 h.	D	H	0	192 h	-1	1
5	AT2 0C	E	0C	0	130	-1	1
6	At2 h.	F	H	0	29	-1	1

1. Regression Analysis

In this experimental study, an empirical model was developed through the regression analysis to correlate the metallurgical parameters to the response Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation. The estimated regression coefficients in Ultimate tensile strength (UTS-MPa), 0.2% proof yields strength and % elongation regression equations (1)-(3) shows that the following parameters; i.e., Pre-aging Temperature (PA T^0C), Pre-aging time (PA t h), Aging time (At2 h), has noteworthy influence on the Ultimate tensile strength (UTS-MPa) and 0.2% proof yields strength. The p – value for these parameters shows that the values are below the accepted value of 0.05. For Ultimate tensile strength (UTS-MPa) and 0.2% proof yields strength regression model, The R – Sq value given is 52.8% and 70.5%, respectively. On the other hand The R – Sq value for the % elongation regression model is 37.9% and only the aging time parameters has a significant effect on the % elongation.

UTS (MPa) = 333 + 0.740 PA T 0C + 3.39 PA t h - 0.224 AT1 0C + 0.440 At1 h. - 0.31 AT2 0C + 0.35 At2 h (1)

YS (MPa) = 285 + 0.739 PA T 0C + 3.46 PA t h + 0.011 AT1 0C + 0.380 At1 h. - 0.114 AT2 0C - 0.70 At2 h (2)

E(%) = 1.10 + 0.00212 PA T 0C - 0.0055 PA t h - 0.00196 AT1 0C + 0.00350 At1 h. - 0.00377 AT2 0C + 0.0195 At2 h (3)

2. Mathematical Model (Factorial DOE and ANOVA Results)

Mathematical models (4)-(6) are developed to relate the alloy Ultimate tensile strength (UTS-MPa), 0.2% proof yield strength and % elongation with the different metallurgical parameters (as mentioned above) to acquire an understanding of the effect of the variables and their interactions on the mechanical properties of 7075 Al-alloys. Within the variation range of the variables studied, this model may be used to predict the alloy % elongation for heat treated 7075 alloys. From the values under the estimated effects coefficients, it is observed that three parameters; has noteworthy influence on the % elongation. Any P-values are below the accepted value of 0.05 have influence on the %elongation, On the other hand, the p – values above the accepted value of 0.05 can be considered to have no influence on the hardness to some extent. The R – Sq value given is 57.1%, 73.8% and 50.8%, respectively.

UTS (MPa) using data in uncoded units = 323.341 + 4.79382* PA T 0C -4.42634* PA t h + 0.84431* AT1 0C + 0.310122* At1 h. - 2.19940* AT2 0C+ 10.9118* At2 h.+ 0.0510012* PA T0C*PA t h – 0.0300270* PA T 0C*AT10C (4)

0.5% offset YS (MPa) using data in uncoded units= 274.858+ 4.92140* PA T 0C -4.57362* PA t h 1.10921* AT1 0C+ 0.246760 * At1 h. -2.06408*AT2 0C + 10.2030*At2 h.+ 0.0522245* PA T 0C*PA t h -0.0309340*PA T 0C*AT1 0C (5)

E(%) using data in uncoded units = 0.913744 + 0.0355221* PA T 0C - 0.182418* PA t h +0.0222419*AT1 0C + 0.00056390* At1 h. - 0.0185398* AT2 0C + 0.0903559* At2 h. +0.00168921 *PA T 0C*PA t h -4.03881E-04* PA T 0C*AT1 0C (6)

3. One Way ANOVA Results

One way ANOVA for UTS and %elongation data results having a confidence level of 95% with different presaging, aging parameters (Time and Temperature) are shown in Fig. 2 for heat treated 7075 Al-Mg-Zn alloy. Figs. 2 (a), (b) show the results for the ultimate tensile strength. On the other hand the results of % elongation are shown in Figs. 2 (c), (d). It is observed from Fig. 3 that an increase in alloy strength is accompanied by a reduction in alloy ductility.

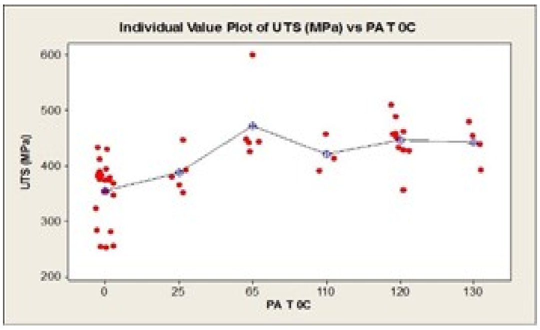

Fig. 2 (a) One Way ANOVA of UTS in terms of Pre-aging temperature

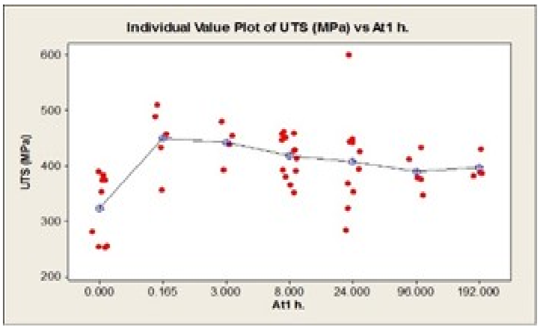

Fig. 2 (b) One Way ANOVA of UTS in terms of aging time

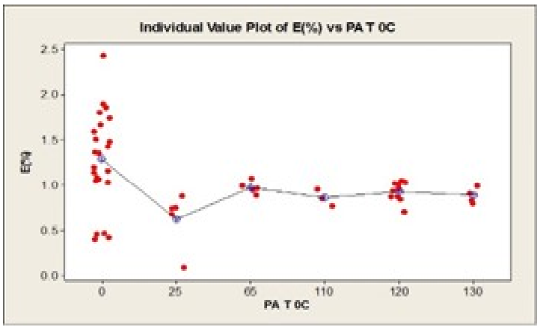

Fig. 2 (c) One Way ANOVA of %E in terms of Pre-aging temperature

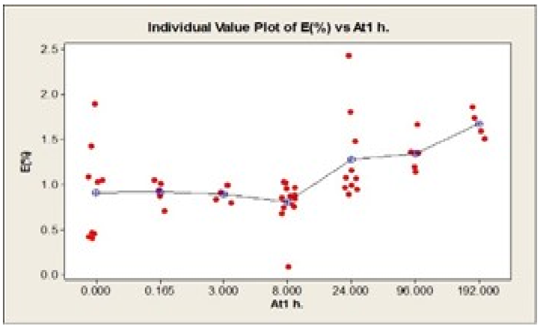

Fig. 2 (d) One Way ANOVA of UTS in terms of aging time

Fig. 2 One Way ANOVA UTS and %elongation data having a confidence level of 95% with different pre-aging and aging parameters (Time and Temperature)

C. Microstructure of 7075 Alloys

The microstructure of as cast Al-Zn-Mg alloy is shown in Fig. 3. This structure was obtained from the ingot which has been cooled quickly to obtain equi-axed network structure. This network structure is made up of particles of several intermetallic compounds formed by combinations of the alloying elements in this alloy. Some of these compounds are soluble while others have slight or practically insolubility. A dendritic microstructure is apparent in all micrographs. Figs. 3 (a)-(c) show a micrograph for as cast microstructure with different magnifications. Similar features of microstructure appear in Figs. 3 (d)-(f) for solution heat treatment conditions. During the solution treatment, the alloy constituents were dissolved.

Fig. 3 (a) Optical micrograph of As-cast Al-ZnMg7075 alloy, 50X

Fig. 3 (b) Optical micrograph of As-cast Al-ZnMg 7075 alloy, 100X

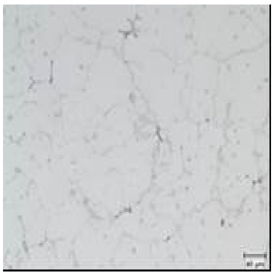

Fig. 3 (c) Optical micrograph of As-cast Al-ZnMg 7075 alloy, 200X

Fig. 3 (d) Optical micrograph of SHT Al-Zn-Mg 7075 alloy, 50X

Fig. 3 (e) Optical micrograph of SHT Al-Zn-Mg 7075 alloy, 100X

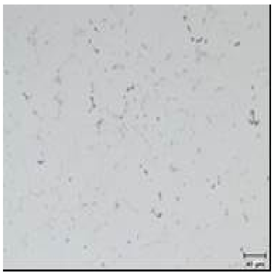

Fig. 3 (f) Optical micrograph of SHT Al-Zn-Mg 7075 alloy, 200X

Fig. 3 Optical micrograph of as-cast (a)-(c) and SHT (d)-(f) Al-Zn-Mg 7075 alloy

IV. Conclusions

1. Solution heat treatment for 8hours at 465 °C resulted in a significant improvement in the alloy strength (for example UTS increased from about 250MPa to 380MPa).
2. Aging at room temperature resulted in slight increase in the alloy strength reaching about 400MPa after aging for 192h.
3. Double aging and RRA heat treatment produced the optimum mechanical properties.

Acknowledgment

Financial and in-kind received support from the Deanship of Scientific Research, Vice Rectorate for Post Graduate and Scientific Research, Salman bin Abduaziz University (SAU) is gratefully acknowledged.

References

[1] I.J. Polmear, "Recent Developments in Light Alloys," *Materials Transactions, JIM*, 37(1) (1996), 12-31.
[2] H.Y. Hunsicker, "Development of Al-Zn-Mg-Cu Alloys for Aircraft," *Proceeding Rosenhain Century Conference, Metals Society*, London, (1976), 359-376.
[3] J.T. Staley, "History of Wrought-Aluminium-Alloy Development," *Aluminium Alloys: Contemporary Research and Applications, Treaties on Materials Science andTechnology*, Academic Press, 31 (1989), 3-31.
[4] Patent No. EP0377779B2, "Aluminum Alloy Product Having Improved Combinations of Strength, toughness and Corrosion Resistance," New European Patent Specification, Bulletin 2001/36, 5 September 2001.
[5] N.E. Paton and A.W. Sommer, "Influence of Thermomechanical Processing Treatments on Properties of Aluminum Alloys," *Proceeding Third international Conference onStrength of Metals and Alloys, Metals Society*, London, 1 (1973), 101-108.
[6] A. Yamamoto et al., "Calorimetric and Resistivity Study of formation and Redissolution of Precipitates in 7050 Aluminum Alloy," *Materials Transactions, JIM*, 39 (1) (1998), 69-74.
[7] A. Joshi, C.R. Shastry and M. Levy, "Effect of Heat Treatment on Solute Concentration at Grain Boundaries in 7075 Aluminum Alloy," *Metallurgical Transactions A*, 12 (A) (1981), 1081-1088.
[8] M.E. Fine, "Precipitation Hardening of Aluminum Alloys," *MetallurgicalTransactionsA*, 6 (A) (1975), 625-630.
[9] J.K. Park and A.J. Ardell, "Microstructures of the Commercial 7075 Al Alloy in the T651 and T7 Tempers," *Metallurgical Transactions A*, 14 (A) (1983), 1957-1965.
[10] A. Karaaslan, I. Kaya and H. Atapek, "Effect of Aging Temperature and of Retrogression Treatment Time on the Microstructure and Mechanical Properties of Alloy AA 7075," *Metal Science and Heat Treatment*, 49 (9-10) (2007), 443-447.
[11] J.K. Park and A.J. Ardell, "Effect of Retrogression and Reaging treatments on the Microstucture of Al-7075-T651," *Metallurgical Transactions A*, 15 (A) (1984), 1531- 1543.
[12] S.V. Emani et al., "Double Aging and Thermomechanical Heat Treatment of AA 7075 Aluminum.
[13] A. H. Geisler; "Phase Transformation in Solids", Willey, New York, 1951, p.387.