ISSN:1306-3111
e-Journal of New World Sciences Academy
2009, Volume: 4, Number: 3, Article Number: 1A0026

ENGINEERING SCIENCES
Received: November 2008
Accepted: June 2009
Series : 1A
ISSN : 1308-7231

Özkan Öz
Halil özer
Karabuk University
ooz@karabuk.edu.tr; halil_ozer@hotmail.com
Karabuk-Türkiye

THE EFFECTS OF THE AGING HEAT TREATMENT ON BUCKLING LOAD OF 7075 ALUMINIUM ALLOY RECTANGULAR PLATE

ABSTRACT

In this study, the effects of the aging heat treatment on buckling load and mechanical properties of rectangular plate made with the 7075 Al-alloy are investigated. We consider rectangular plate having two simply supported edges and the other two free edges. The heat treatment performed in this study involves solution treating the alloy at 480°C for 1 h, followed by rapid quenching in water and finally aging at 130°C for a variety of artificially aging times. The main variable chosen in artificial aging treatment is the aging time. Under these conditions maximum critical buckling load value is attained at 130°C for 48 h. The effects of aging heat treatment on microstructure of the alloy were also studied by SEM, EDS and XRD.
Keywords: Aging heat treatment, 7075 Al-alloy,
Buckling of Rectangular Plate, SEM, XRD

YAŞLANDIRMA ISIL İŞLEMİNİN 7075 ALÜMİNYUM ALAŞIM MALZEMELİ DİKDÖRTGEN PLAĞIN BURKULMA YÜKÜ ÜZERİNE ETKİLERİ

ÖZET

Bu çalışmada, yaşlandırma ısıl işleminin 7075 alüminyum alaşımından yapılan dikdörtgen plakların burkulma yükü ve mekanik özellikleri üzerine etkileri incelenmiştir. Plaklar için sınır şartı iki kenarı basit mesnetli ve diğer iki kenarı serbest olarak alınmıştır. Yaşlandırma ısıl işlemi sırasıyla, 480°C'de 1 saat solusyona alma, suda hızlı soğutma ve 130°C sabit sıcaklıkta farklı zaman aralıkları kullanılarak gerçekleştirilmiştir. Yapılan çalışmada temel değişken olarak yapay yaşlandırma süreleri gözönüne alınmış ve sonuç olarak maksimum kritik burkulma yükü 48 saat yapay yaşlandırma süresinde elde edilmiştir. Ayrıca, yaşlandırma ısıl işleminin mikroyapı üzerindeki etkileri, SEM, EDS ve XRD kullanılarak tespit edilmiştir.
Anahtar Kelimeler: Yaşlandırma Isıl İşlemi, 7075 Al-alaşımı,
Dikdörtgen Plağın Burkulması, SEM, XRD

1. INTRODUCTION (GİRİŞ)

The linear elastic buckling of the Al-alloy rectangular plate is an important research subject due to its relation to ocean, aerospace, mechanical and civil engineering applications. Buckling analysis is very important especially in weight sensitive industries for the structural elements subjected to in-plane compressive loads. There is an ever-increasing demand for the use of the Al-alloys due to their high strength to weight ratio in comparison with steel. Several effects in the aging heat treatment have been studied on the mechanical properties of Al-alloy in the literature. In the context of applying the solution heat treatment to 7xxx-series Al-alloy, Clark et all [1] studied the influence of varying the thermal processing parameters, which are solution treatment temperatures, quenching media and artificial aging conditions, on the physical and mechanical properties of 7075-T6 aluminum alloy and found an excellent correlation between the tensile strength and hardness. Iskandar et all [2] studied some variables in the heat treatment processes of the 7249 aluminum alloy. These variables are solution treatment temperatures (445-505 °C), quenching media (water, 20% polyalkylene glycol, and air), natural aging times (0,4, and 168 h) and artificial aging temperatures (111, 121, and 131 °C). They identified that quenching is the most critical step in the process. Viana et all [3] studied retrogression and re-ageing of 7075 Al alloy. They showed that the greater the retrogression temperature, the more stable is the microstructures obtained after re-ageing. El-Baradie and El-Sayed [4] applied two double thermomechanical treatment process to a thick plate cast from 7075 Al alloy. They proposed a new technique called as FA-ITM. This method contains four steps as solid solution heat treatment, over-aging, hot and cold-rolling, and recrystalization. Their studies led to improvement in strength and ductility simultaneously. Wang et al [5] studied the microstructure and properties of 7075 aluminum alloy at different aging up to 48 h using hardness test, tensile test, electrical conductivity measurement, XRD and TEM microstructure analysis. Ozer [6] studied variational formulation and analysis of polar orthotropic circular plates using an energy principle.

Buckling problem of the rectangular plates can be found in many papers and standard texts [7, 8 and 9]. Supasak and Singhatanadgid [10] determined critical buckling load of aluminum rectangular plates by using four different experiment methods and presented the advantages and disadvantages of each method. Easton et all [11] compared the deformation of magnesium alloys with aluminum and steel in tension, bending and buckling. Although considerable analytical and experimental work has been performed on the buckling of rectangular plate, the effect of aging heat treatment on the buckling load is not available in the open literature and it still remains open.

The main aim of the research described in this paper is to experimentally obtain the effect of aging heat treatment on the buckling load of the rectangular plate made with the 7075 Al-alloy. We consider rectangular plate having two simply supported edges and the other two free edges. The 7075 Al-alloy is heat treated in three-step processes: solution heat treatment (SHT) at 480°C for 1 h, quenching in water, and aging at 130°C for a variety of artificially aging time portions. The effects of aging treatment on mechanical properties of the alloy were also studied. The obtained results are graphically summarized and some conclusions are drawn.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Critical buckling load of the Al-alloy rectangular plate is an important research subject due to its relation to ocean, aerospace, mechanical and civil engineering applications. Buckling analysis is very important especially in weight sensitive industries for the structural elements subjected to in-plane compressive loads. There is an ever-increasing demand for the use of the Al-alloys due to their high strength to weight ratio in comparison with steel. However there is no competence information available for the designer about the effect of the aging heat treatment on the buckling load in the open literature. In this paper, this effect is considered and experimental results are given.

3. EXPERIMENTAL PROCEDURES OF THE AGING HEAT TREATMENT (YAŞLANDIRMA ISIL İŞLEMİNİN DENEYSEL PROSEDÜRÜ)

The 7075 Al alloy was supplied in large sheet with a thickness of 6-mm. The dimensions of the rectangular plate were 45 mm wide and 180 mm length. The chemical composition of the sheet analyzed through spectral analysis with Was (Foundary Master) machine in Alkor Casting Company in Turkey and ranges of the alloying elements in weight percentage listed in Table 1. It is seen from Table 1 that the chemical composition of the Al-alloy is in the range of standards [12].

Table 1. Chemical composition of the 7075 Al alloy
(Tablo 1. 7075 alüminyum alaşımının kimyasal kompozisyonu)

Elements	Fe	Cu	Mn	Mg	Zn	Cr	Ti	V	Zr	B	Al
Wt.%	0.196	1.561	0.0687	2.734	5.9	0.2	0.0343	0.0066	0.0091	0.0025	bal.

The solution heat treatment performed in this study involves solution treating the alloy at SHT temperature for a sufficient time until the alloying elements taken into the solid solution, followed by rapid quenching in water and finally age hardening at a given temperature for a variety of artificially aging time portions. The heat treatment stages followed in this study illustrated in Figure 1.

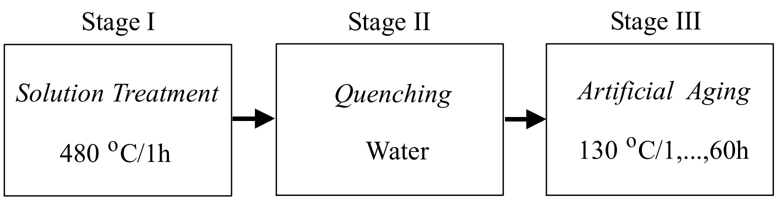

Figure 1. The heat treatment stages
(Şekil 1. Isıl işlem aşamaları)

In Stage I, the Al-alloy was heated to 480 °C, where the material was held at this temperature for 1 h in a temperature-controlled furnace (Protherm), and the solid solution formed at this temperature. Then, in quenching step (Stage II) all the solution heat treated specimens cooled rapidly from SHT temperature to room temperature in water so as to preserve the supersaturated solid solution. Next, the specimens are kept in a freezer to maintain this supersaturated state within material and to avoid natural aging of the alloy at room temperature. Finally, to form finely dispersed precipitates the 8 aging heat treatments (Stage III) were performed in another furnace (Nüve Fn 055) at constant aging temperature of 130 °C for a variety of artificially aging times (Table 2). After aging process performed, the specimens were cooled from the aging temperature to room temperature.

Table 2. Thermal processing to produce 8 conditions
(Tablo 2. Sekiz ürünün sıcaklık işlemesi)

Solution Treatment (°C/1h)	Quenching Medium	Artificial Aging Treatment	
480	Water	01	130°C/1h
		02	130°C/2 h
		03	130°C/4 h
		04	130°C/8 h
		05	130°C/15 h
		06	130°C/30 h
		07	130°C/48 h
		08	130°C/60 h

After completing the heat treatment process, to investigate the effects of aging heat treatment on buckling loads of the rectangular plate and mechanical properties of the alloy some tests performed on aged and non-aged Al-alloy specimens. All the test results given and discussed in the section of the results and discussion.

4. BUCKLING OF THE RECTANGULAR PLATE (DİKDÖRTGEN PLAĞIN BURKULMASI)

Buckling of rectangular plate having two simply supported edges and the other two free edges subjected to uniaxial end compression along its longitudinal direction is considered. Geometry, loading and boundary conditions of the plate are shown in Fig. 2.

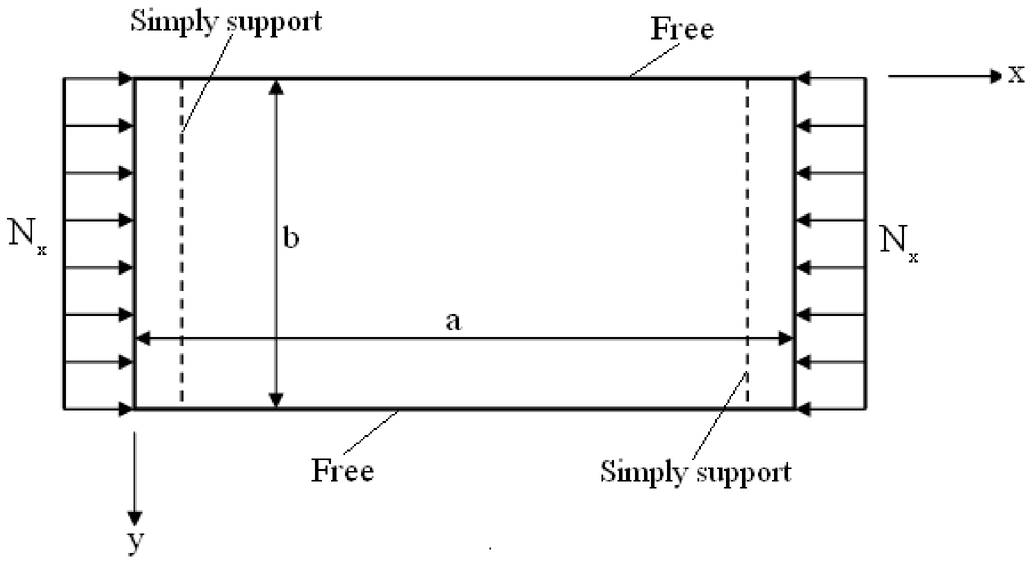

Figure 2. Geometry, loading and boundary conditions of the plate
(Şekil 2. Levhanın yükleme ve sınır şartları geometrisi)

Uniaxial compression tests carried out on the plate with aged and non-aged. Buckling tests were performed on a Zwick/Roell Z050 testing machine. Prior to the testing the ends of each specimen were machined carefully to give plane ends. Buckling tests were carried out in the rolling direction. The compression testing was performed at a rate 0.5 mm/min.

The magnitude of compressive load at which the plate becomes unstable called “critical buckling load”. One of the important issues considered in the experiment involves in the method of identifying a buckling load of the test specimens. There are several techniques of identifying the buckling load in the experiment [10]. In the present study Zwick/Roell Z050 testing machine gives us graphically a plot of compressive load vs. compressive strain. The buckling load determined from a bifurcation point, at which buckling load is reached, in the load-strain graphic.

5. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

Prior to the buckling tests, firstly the influence of aging treatment on the tensile strength, yield strength and hardness of 7075 Al alloy was studied. Three specimens were used for each aging heat treatment condition in defining the mechanical properties of the alloy. Therefore, seventy-two specimens were used in these tests. The alloy was machined into tensile bars by following ASTM E 8M specifications. Tensile properties are tested using an Zwick/Roell Z050 universal testing machine. This machine is also used to define the critical buckling loads of the rectangular plates. The tensile tests were carried out in the rolling direction. Hardness measurements are conducted with a Vickers (HV2) scale using Affri System. The results of the mechanical properties of aged Al-alloy are presented in Table 3.

Tablo 3. Mechanical properties of the aged Al-alloy versus artificial aging treatment
(Tablo 3. Yaşlandırılmış alüminyum alaşımının mekanik özellikleri)

Artificial Aging Treatment			Yield Strength (MPa)	Tensile Strength (MPa)	Hardness (HV2)
	01	130°C/1h	272	443	123
	02	130°C/2 h	308	448	124
	03	130°C/4 h	367	481	165
	04	130°C/8 h	420	500	173
	05	130°C/15 h	452	531	197
	06	130°C/30 h	483	538	202
	07	130°C/48 h	491	551	210
	08	130°C/60 h	453	506	193

As seen in Table 3 the mechanical properties of the Al-alloy have improved by increasing the artificial aging hours from 1 to 48 h, whereas the ductility has decreased. Further increase in aging time after 48 h has reduced the mechanical properties of the alloy. The strength and hardness values showed similar trends.

Secondly, we studied the effect of aging treatment on the buckling load of the alloy. Experimental buckling load of the non-aged Al-alloy obtained as 450 kN/m from buckling test. After completing buckling tests for non-aged Al-alloy we performed the buckling tests on aged plates. Twenty-four specimens were used in the buckling tests by using 3 specimens for each aging heat treatment condition.

The effect of the aging time at constant aging temperature on the buckling load of the rectangular plate is presented in Figure 3. It can be observed that the specimens showed a continuous increase in their buckling loads by increasing the artificial aging hours from 1 to 48 h. The buckling load reaches a peak at the 48 h of artificial aging. After the 48 h of artificial aging, the buckling loads of the specimens decreased.

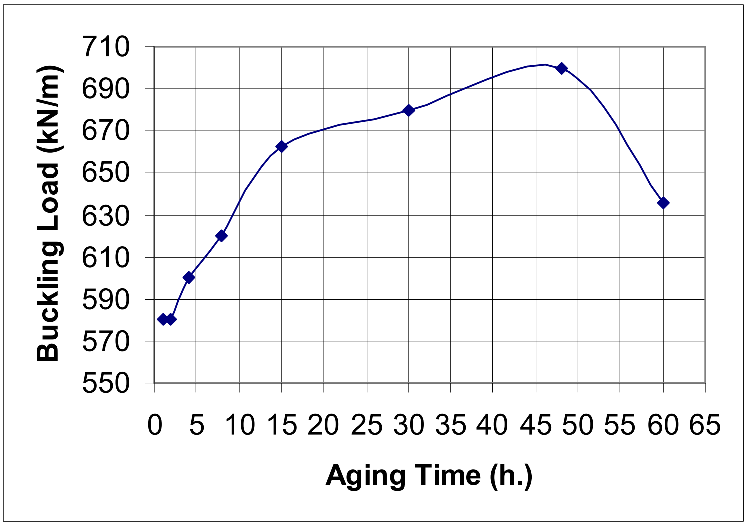

Figure 3. Buckling test results of the aged 7075 Al-alloy rectangular plate
(Şekil 3. Yaşlandılmış 7075 alüminyum alaşımlı dikdörtgen plakanın test sonuçları)

It is seen from Fig. 3 that the buckling load values increased by around 21% by increasing the artificial aging hours from 1 to 48 h. The alloy achieves its maximum buckling load at 130°C when aged for 48 h. Beyond this time barrier a decrease occurs in the buckling loads as the aging time increase at constant aging temperature. There is around 9% drop in the buckling load values with the increase in artificial aging time from 48 h to 60 h. The aging time portion of 48 h is identified to be the most critical time in these tests for the optimum buckling load. An increase in buckling load of around 55.46% achieved by aging at 130°C for 48 h over non-aged Al-alloy.

It is seen from the above that aging response of the alloy is very quick, especially after 2 h of aging. During aging, the solid solution decomposes and precipitation occurs. For 7xxx series Al alloys, these precipitates are made up mainly of $MgZn_2$. Increasing of the mechanical properties and buckling load of 7075 Al-alloy is related with the formation of $MgZn_2$ precipitates in the microstructure during aging. The presence of these precipitates increases the buckling load and the strength of the alloy, but reduces the ductility (Table 3, Figure 3). As the artificial aging time increases after 48 h, a steadily decreasing mechanical properties and buckling load is observed. The reason for this is that, the size of the individual particle increases in over-aging of the Al-alloy, but the number of particles decreases. The heat-treated specimen with aged for 48 h was analyzed through EDS and illustrated using SEM (Figure 4a and Figure 4b).

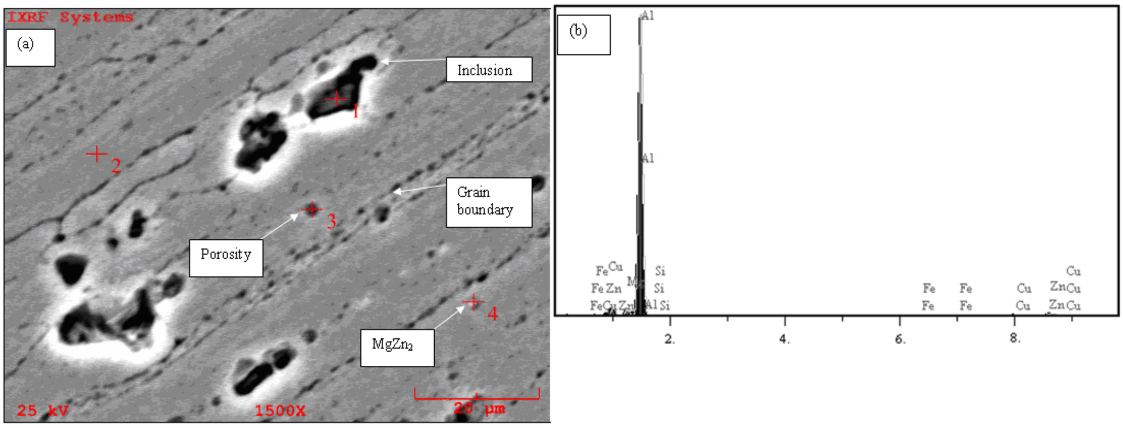

Figure 4a. SEM micrograph of the 7075 Al-alloy aged at 130˚C for 48 h
Figure 4b. EDS analysis of the particle numbered as 4 in Figure 4a
(Şekil 4a. 7075 Alüminyum alaşımın 130°C sıcaklıktaki 48 saatlik SEM görüntüsü)
(Şekil 4a. Şekil 4a'nın EDS analizi)

It is seen from Fig. 4a that grain boundaries have an extended form on the rolling direction. XRD pattern of 7075 Al alloy at peak aged condition (48 h at 130°C) shown in Figure 5. Furthermore, SEM micrograph and XRD pattern show the existence of spherical shaped $MgZn_2$ (Figure 4a, Figure 5).

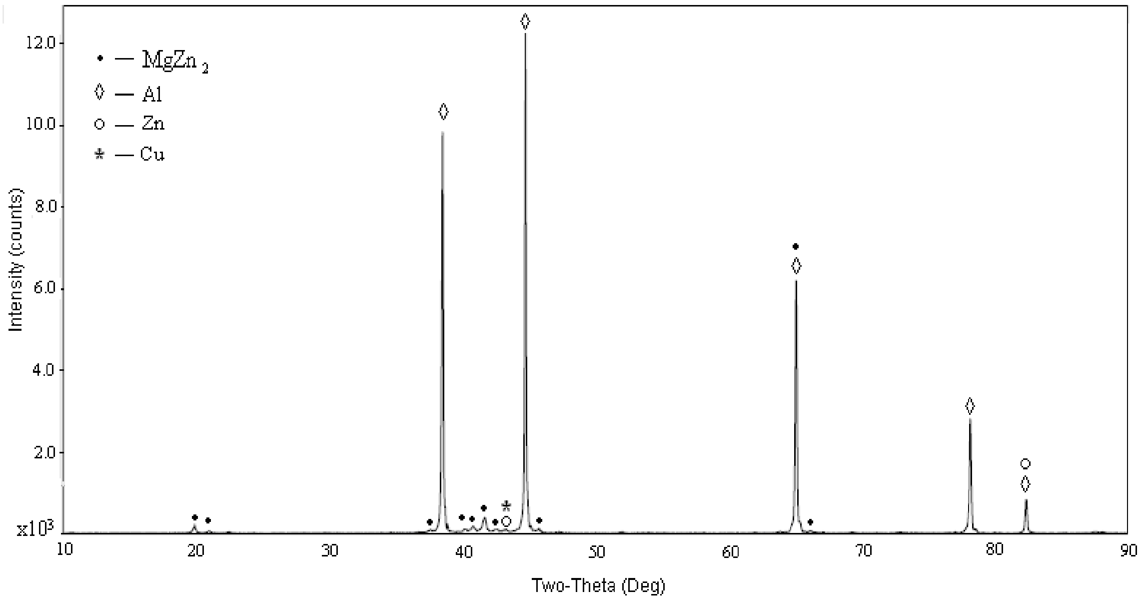

Figure 5. XRD pattern of 7075 Al alloy aged at 130˚c for 48 h
(Şekil 5. 7075 Alüminyum alaşımın 130°C sıcaklıktaki 48 saatlik XRD deseni)

SEM, EDS and XRD results given in Figs. 4-5 indicate that the metastable η' ($MgZn_2$) precipitates form at the peak aged condition of artificial aging. Precipitation formation of 7xxx series Al alloys during single aging treatment can be defined as: Solid solution $\rightarrow$ GP zones $\rightarrow$ Metastable $\eta' \rightarrow$ Stable η ($MgZn_2$). Increasing strength of the aged alloy concerned to forming of GP zones and the metastable η' instead of stable η phase. In addition formation and growth of GP-zones in aluminum alloys can be evaluated by the measurement of hardness related to the aging time. A good correlation exists between the η' precipitates and Vickers (HV2) hardness during aging at 130°C, which confirms that the η' precipitates are responsible increasing in hardness for the peak aged condition [13, 14, 15 ve 16].

These test results provide evidence that the mechanical properties and buckling load of the alloy changes in relation to the aging time. All the aged rectangular plates carried more buckling load than the non-aged. The experimental results have revealed that aging at 130 °C for 48 h is the most suitable combination of time and temperature to reach the optimum buckling load for heat treatment performed here.

6. CONCLUSION (SONUÇ)

There is no competence information available for the designer about the effect of the aging heat treatment on the buckling load in the open literature, so this effect is addressed here. The variation of artificial aging times appeared to have significant effects on the buckling load values.

ACKNOWLEDGEMENTS (TEŞEKKÜR)

The authors would like to thank assistant professor Dursun Ozyurek of Karabuk University for the helps related to this paper.

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