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Test Matrix for Heat Exposure of Aluminum Alloys at Various Times and Temperatures

A. Al-Abduljabbar[1, a], O.S. Es-Said[2, b]

[1] Mechanical Engineering Department, King Saud University., Riyadh, Saudi Arabia

[2]Mechanical Engineering Department, Loyola Marymount University, Los Angeles, CA 90045-8145, USA

[a] ajabbar@ksu.edu.sa, [b] oessaid@lmu.edu

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Abstract. The purpose of this study is to characterize the effects of heat damage on the electrical conductivity and static mechanical properties of aluminum alloys. The data resulting from the experiments of thermal exposure of several aluminum alloys are used to model the relations that describe the dependence of the electrical conductivity and hardness on the two main variables of these experiments: the temperature and the time of exposure. The dependence of yield strength and ultimate tensile strength on hardness values is characterized. For each case, different materials (alloys) exhibit similar general trends although there are different coefficients for each material to satisfy the general relation.

Introduction

High strength, age-hardenable Aluminum alloys are commonly used in the aerospace industry for their optimal combination of physical and mechanical properties. Among these properties are alloy strength, ductility, fatigue resistance, fracture toughness, and corrosion resistance. The correct combination of alloy composition and thermal mechanical processing is essential to obtain the desired set of alloy properties [1].

When components are in service within the aircraft, alloys could be subjected to thermal excursions beyond industry accepted limits, such as fire damage, impingement of engine exhaust, or other sources [2, 3]. This can compromise the structural integrity of the aircraft component. Nondestructive inspection (NDI) methods, such as electrical conductivity measurements, and non-detrimental mechanical testing techniques, such as hardness tests, are used to assess the extent of heat damage. NDI is used in order to avoid disassembling the component in question and conducting destructive tests, which will render the component unusable. While these techniques are commonly used in the aerospace industry, they suffer from insufficient data correlating electrical conductivity and hardness to alloy strength of different alloys [4, 5, 6, 7].

A previous work sought to correlate thermal exposure to electrical conductivity, hardness, yield strength, and ultimate tensile strength data in order to facilitate the disposition of aircraft exposed to thermal excursions [7]. The alloys and tempers examined included 2014-T6, 2024-T3, 6061-T6, 7050-T7451, and 7075-T6. The alloys were thermally exposed at 177^{o}C (350^{o}F), 204^{o}C (400^{o}F), 260^{o}C (500^{o}F), 316^{o}C (600^{o}F), 371^{o}C (700^{o}F), 427^{o}C (800^{o}F), 482^{o}C (900^{o}F) for 1 min, 10 min, 30 min, 1 hour, 3 hours, 10 hours, 1 day, 10 days, and 20 days. The details of this study are explained in Reference [7].

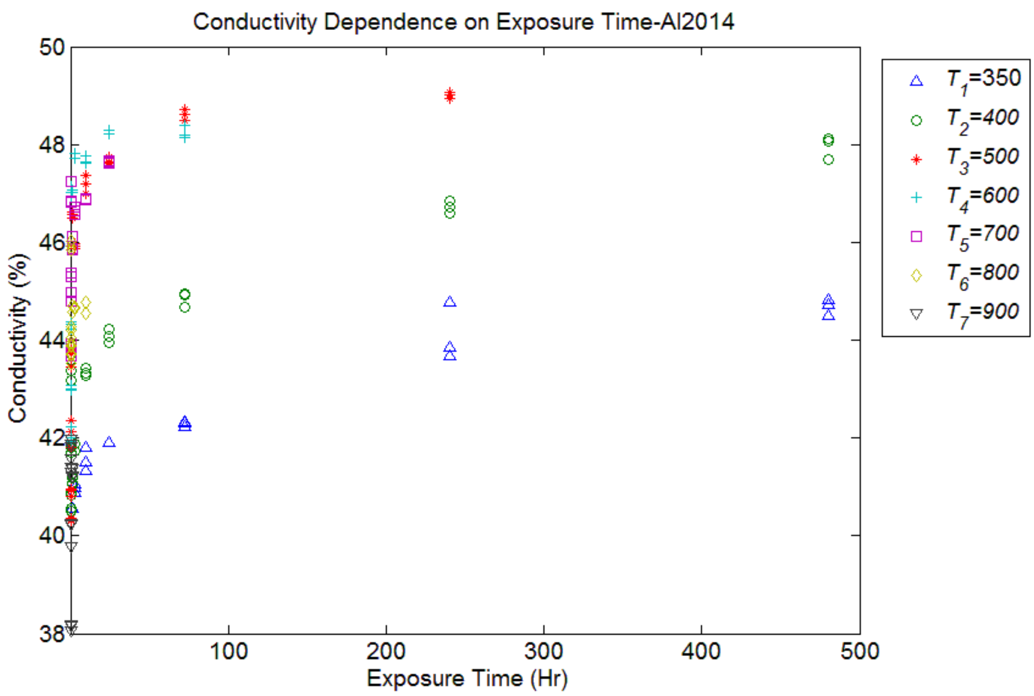
In this work, correlations are proposed between the physical properties (electrical conductivity), and the mechanical properties (hardness, yield strength, and tensile strength) to the temperature and time of the thermal exposure.

Analysis

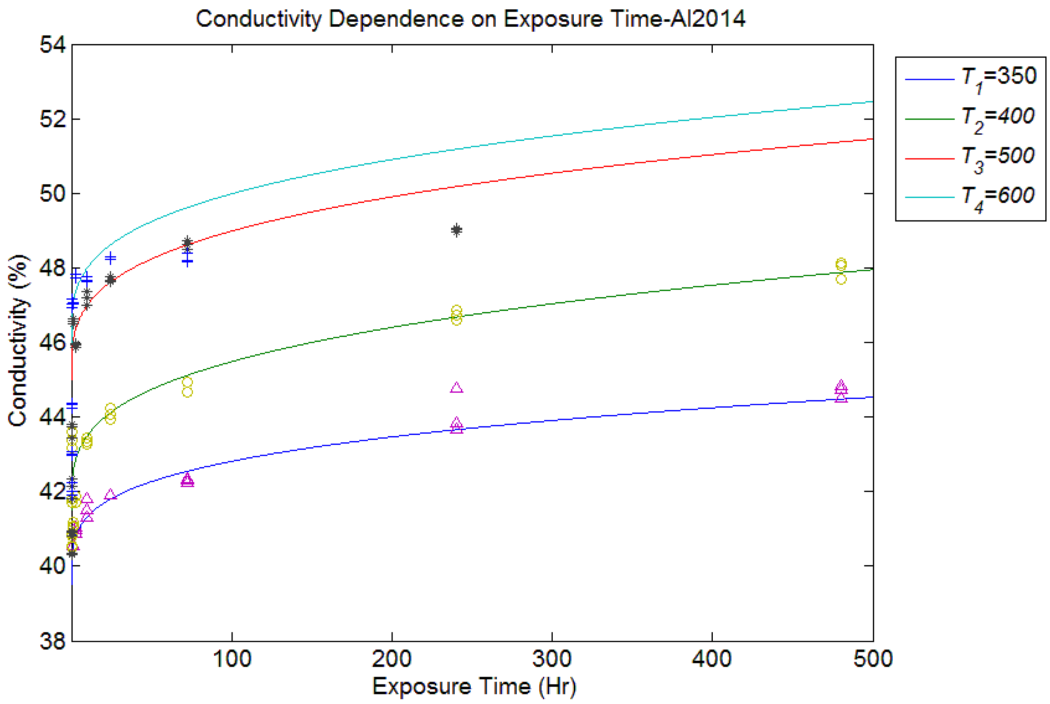
The effect of exposure, time, and temperature on the conductivity and hardness values will be considered. Then, the hardness measurements will be correlated to the yield and ultimate strength values of the different alloys.

Dependence of Conductivity on Exposure Time and Exposure Temperature

Figure 1 shows plots of conductivity as a function of exposure time for the Al-2014 alloy system. The plot is produced for different contours of exposure temperatures. The same trend holds for all other alloys. From the plots, the general trend indicates that the conductivity as a function of both variables can be presented according to the following relation:



(a)



(b)

Figure 1: Conductivity as a function of exposure time for different exposure temperatures for Al2014

$$c = A + t_a^{a} \qquad (1)$$

where:

c: Conductivity
t_a: Exposure time
A: Temperature dependent parameter
α: Temperature dependent exponent

The parameters A and α depend on the exposure temperature and are different for each curve and for each alloy system.

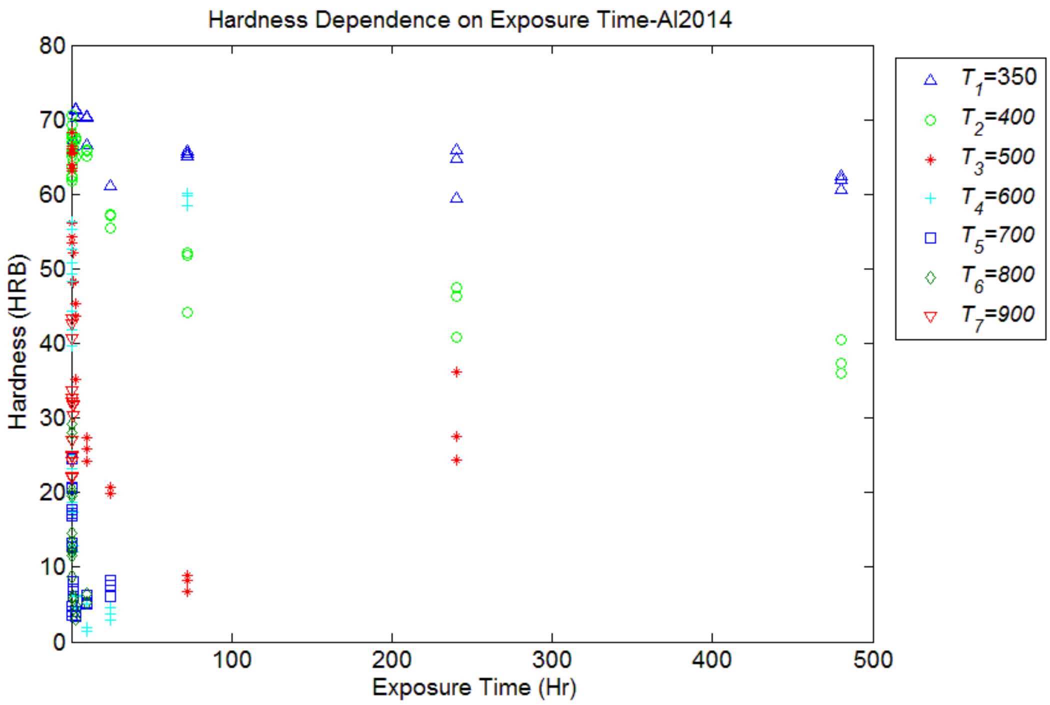
Dependence of Hardness on Exposure Time and Exposure Temperature

Figure 2 shows a plot of hardness values as a function of exposure time for the Al2014 alloy system. The plot of hardness versus exposure time is produced for different contours of exposure temperature. The same trend holds for all other alloys. The general relation shows the dependence of hardness values on exposure time to be a negative exponential, according to the following relation

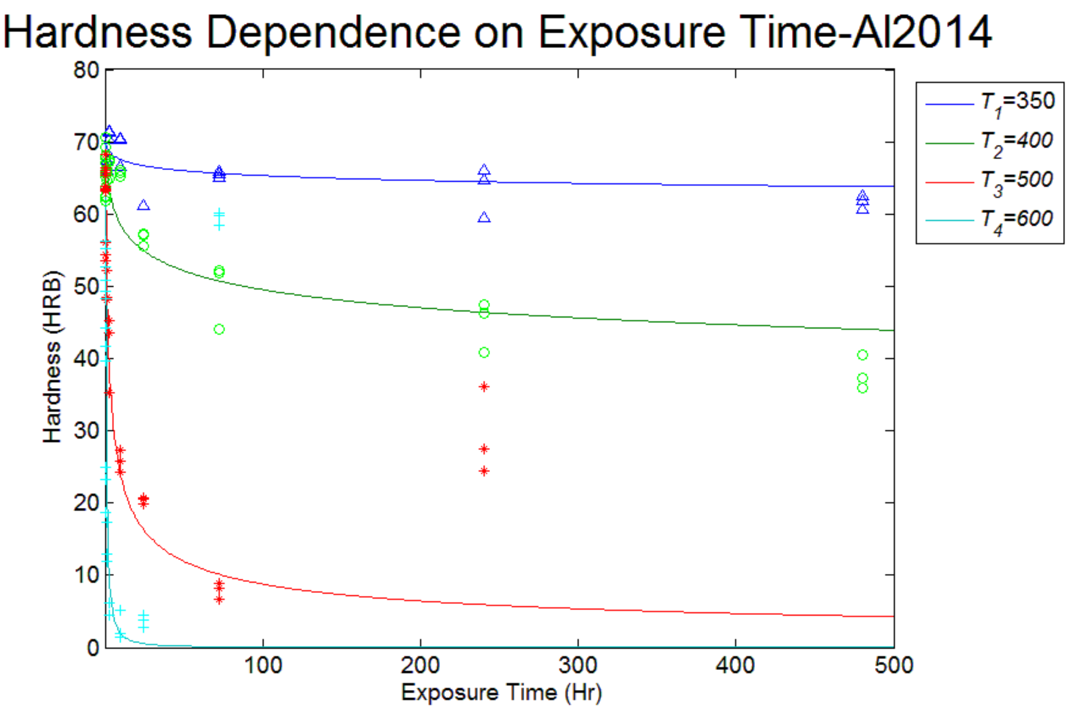
$$H = B * (t_a+1)^{-\beta} \qquad (2),$$

where:

H: Hardness
t_a: Exposure time
B: Temperature dependent parameter
β: Temperature dependent exponent



(a)



(b)

Figure 2: Hardness as a function of exposure time for different exposure temperatures for Al2014.

Dependence of Yield and Tensile Strength on the Hardness Measurements

The yield strength and ultimate tensile strength data were correlated to the hardness measurements of all of the alloy systems. Except for the 6061- T6 alloy system, the trend of all other alloy systems followed relations of the form:

$$\log \sigma_y = a + b\,H \quad (3)$$

$$\sigma_u = c + d\,H \quad (4)$$

Where σ_y is the yield strength, σ_u is the ultimate tensile strength, H is the hardness, a and c are intercepts, and b and d are slopes. Figure 3 shows a plot of yield and ultimate strength values VS hardness for Al7075 alloy system.

The coefficients and correlation values are listed in Table 1. It is clear that these relations hold very well to all of the alloy systems except for the Al6061-T6.

Table 1: List of Coefficients for the different alloys

Alloy	Variable	Slope (m)	Intercept (B)	R^2
Al2014	$\log \sigma_y$	**0.0285**	**1.7288**	**0.8457**
	σ_u	**0.6062**	**13.4342**	**0.9551**
Al2024	$\log \sigma_y$	**0.0199**	**2.3214**	**0.9558**
	σ_u	**0.4492**	**28.7848**	**0.9565**
Al6061	$\log \sigma_y$	**0.0009**	**2.6750**	**0.0007**
	σ_u	**0.0039**	**26.8372**	**0.0001**
Al7050	$\log \sigma_y$	**0.0160**	**2.6030**	**0.7863**
	σ_u	**0.4181**	**29.6203**	**0.7280**
Al7075	$\log \sigma_y$	**0.0194**	**2.3645**	**0.9630**
	σ_u	**0.4854**	**27.1251**	**0.9161**

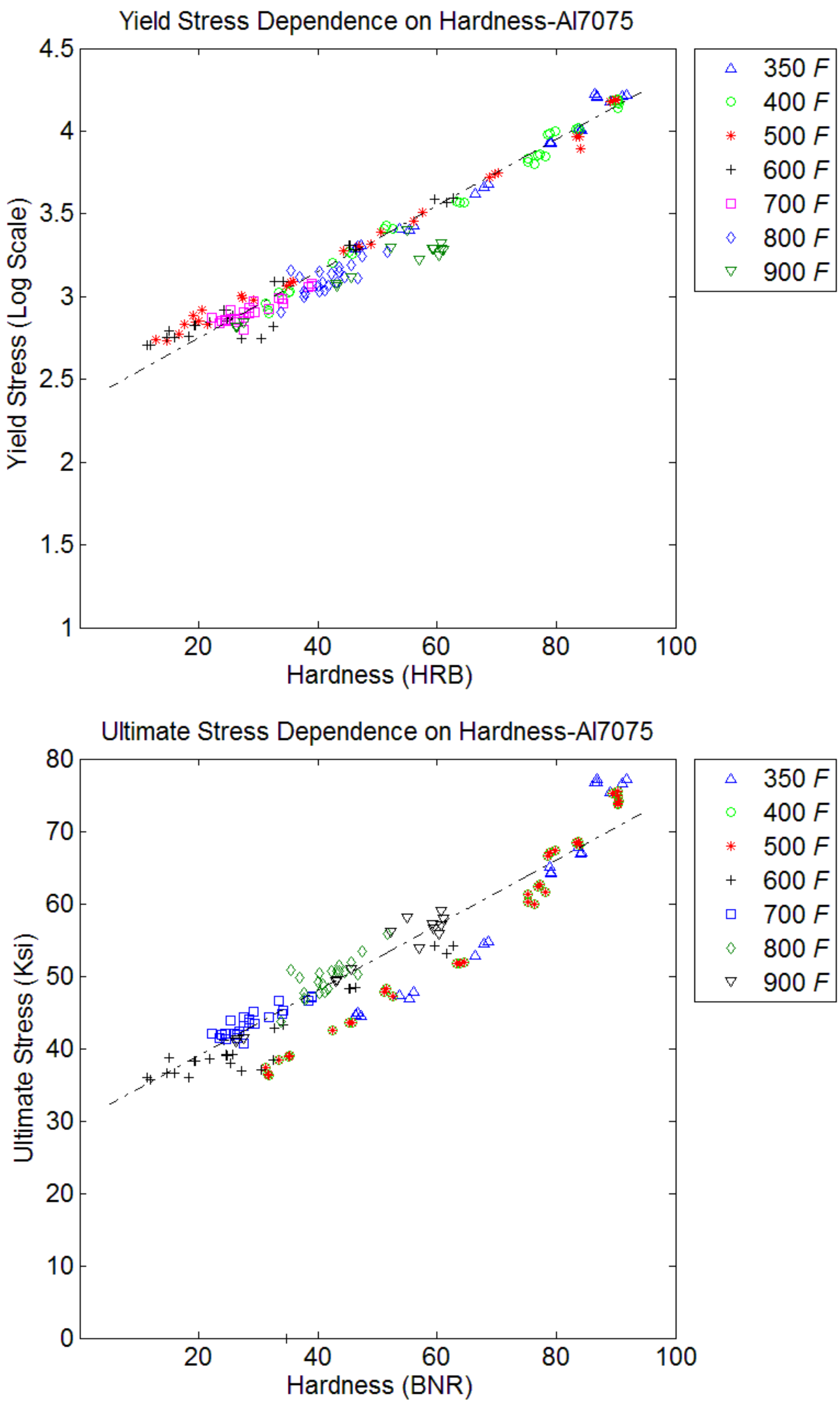


Figure 3: Yield and Ultimate strength values VS hardness values.

Conclusions

1. Conductivity is an exponential function of exposure time for a certain exposure temperature. Function constant and exponent depends on exposure temperature.
2. Hardness is an exponential function of exposure time with negative exponent. Similar to the case for conductivity, constants depend on exposure temperature.
3. The dependence of the log of the yield strength versus hardness follows a linear relationship. The dependence of the ultimate tensile strength versus hardness also follows a linear relationship. Al6061-T6 is the only exception to this trend.

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