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Cooling Rate Influence of Annealing Process on The Tensile Properties of Aluminum Alloy 7075

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Abstract: *This study aims to investigate the effect of cooling rate of annealing process on the tensile properties and the fracture surface of 7075 aluminum alloy. It is found that the yield strength, ultimate tensile strength, fracture strength, modulus of resilience, modulus of toughness, and ductility increase with decrease the cooling rate. The results reveal that the cooling in the furnace creates a 7075 aluminum alloy with high tensile properties, whereas the cooling in furnace to 250 ^{0}C, then air creates a 7075 aluminum alloy with low tensile properties. It may be concluded that the tensile properties of the aluminum alloy 7075 dependent on the cooling rate of annealing process.*

Keywords: Annealing-heat treatment, tensile properties, 7075 aluminum alloy, fracture surface

1. INTRODUCTION

7xxx and 6xxx series aluminum alloys have been studied extensively because of their good properties such as high strength, weldability, formability, corrosion resistance, and low cost [1]. Aluminum alloys 6082 and 7075 among other alloys of the 6000 and 7000 series are two of the most important high strength alloys used in aerospace and aviation industries because of their exceptional mechanical and physical properties [2, 3]. Aluminum alloy 7075 T6 was reported to be one of the commercially available aluminum alloys featuring highest strength [4].

The anneal-temper aluminum alloys are the most widely used conditions owing to their high room-temperature plasticity compared to other temper conditions. Several scientists have analyzed the annealed secondary phase or/and texture evolution in aluminum alloys, such as Al/Mg alloy and Al/Cu alloy. However, the annealed secondary phase and texture evolution of aluminum alloy 7075 was barely reported [5]. Aluminum-zinc alloy as it is in 7075 aluminum alloy is susceptible to embrittlement because of micro segregation of $MgZn_2$ precipitates which may lead to catastrophic failure of components produced from it. The alloy is also susceptibility to stress corrosion cracking [6].

The optimum properties of aluminum are achieved by alloying additions and heat treatments. This promotes the formation of small hard precipitates which interfere with the motion of dislocations and improve its mechanical properties [7-9]. The heat-treating which are applied in the aluminum alloys 7075 are solution heat-treating, annealing, aging, over aging, duplex aging, retrogression and re-aging [10]. Heating to decrease strength and increase ductility (annealing) is used with alloys of both types; metallurgical reactions may vary with type of alloy and with degree of softening desired [11].

The objective of the study is to investigate the effect of cooling rate of annealing process heat treatment on the yield strength, ultimate tensile strength, fracture strength, ductility, modulus of resilience, and modulus of toughness of 7075 aluminum alloy.

2. EXPERIMENTAL

2.1. MATERIALS

The material used in this study is 7075 aluminum alloy. The chemical composition of 7075 aluminum alloy is given in Table 1.

Table 1: Chemical composition of 7075 aluminum alloy, (wt. %)

Al	**Zn**	**Mg**	**Cu**	**Cr**	**Fe**	**Si**	**Mn**
89.5	5.54	2.46	1.93	0.245	0.126	0.113	0.025

2.2. HEAT TREATMENT

The type of heat-treatment employed in this study is namely annealing-heat treatment. Heat-treatment specimens are positioned in an electrical furnace. The heating temperatures, the holding time, and cooling method will be described in the heat-treatment schedule in Table 2.

Table 2: Heat-treatment schedule

Temperature, ^{0}C	Holding time, hours	Cooling method
450	2	1. Cooled in furnace to 250 ^{0}C, then air
		2. Cooled in furnace to 150 ^{0}C, then air
		3. Cooled in furnace

2.3. TENSILE TEST

Cylindrical tensile test specimens of 40 mm gauge length and 8 mm diameter are used to evaluate the tensile properties of the specimens. Tension test was carried out at room temperature on Universal Testing Machine with a cross-head speed of 5 mm/min. Figure 1 shows the shape and dimensions of the tensile specimens used in this study. All dimensions are in mm.

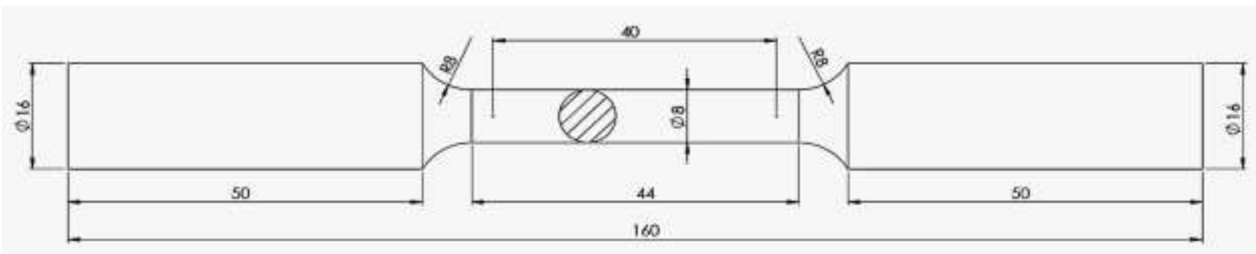

Figure 1. The shape and dimensions of the tensile specimens

2.4. FRACTURE SURFACE EXAMINATION

The specimens for fracture surface examination are sectioned after the finishing of tensile test. Fracture surfaces of the specimens used in this study are examined by optical microscopy. The observations are focused on the fracture mode change from one cooling method to another.

3. RESULTS AND DISCUSSION

3.1. TENSILE PROPERTIES

The yield strength (proportional limit) of 7075 aluminum alloy as a function of the cooling method is indicated in Figure 2. It is clear that the aluminum alloy 7075 cooled in the furnace has the highest value of the yield strength (σ_y = 214.3 MPa), followed by the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air (σ_y = 208 MPa), whereas the aluminum alloy 7075 cooled in furnace to 250 ^{0}C, then air shows the minimum yield strength (σ_y = 190 MPa). This can be explained by the rate of cooling, slow cooling in the furnace may lead to the separation or precipitation of some metallic phases, which lead to an increase in the yield strength. This means that the aluminum alloy 7075 cooled in the furnace has the higher withstand to deform which led to failure.

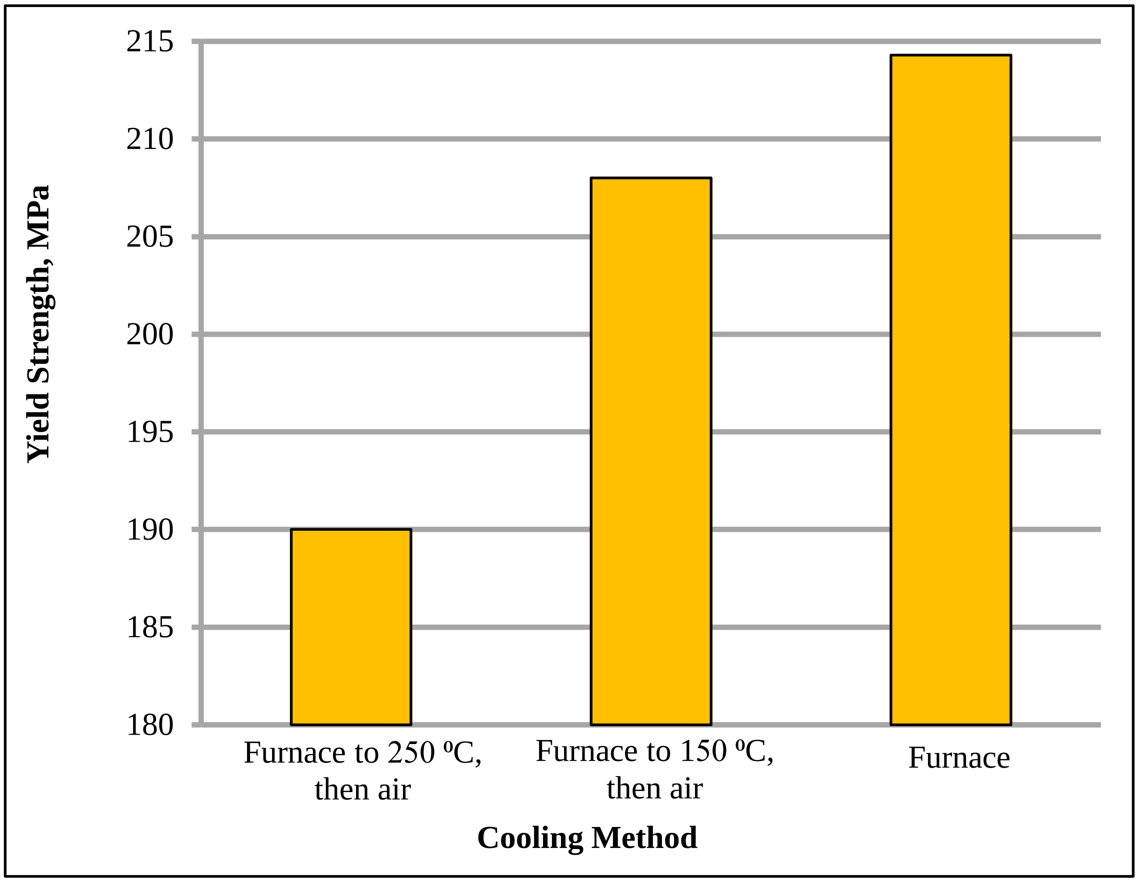

Figure 2. Effect of the cooling method on the yield strength for 7075 aluminum alloy

Figure 3 shows the ultimate tensile strength of 7075 aluminum alloy as a function of the cooling method. It is clear that the aluminum alloy 7075 cooled in the furnace has the highest value of the ultimate tensile strength (σ_u = 325.7 MPa), followed by the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air (σ_u = 316.7 MPa), whereas the aluminum alloy 7075 cooled in furnace to 250 ^{0}C, then air shows the minimum ultimate tensile strength (σ_u = 310.7 MPa). These observations could be related to the precipitation of some metallic phases, which lead to an increase in the ultimate tensile strength of the aluminum alloy 7075. This means that the aluminum alloy 7075 cooled in furnace enable to withstand the fracture under the tensile loads compared to the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air and in furnace to 250 ^{0}C, then air.

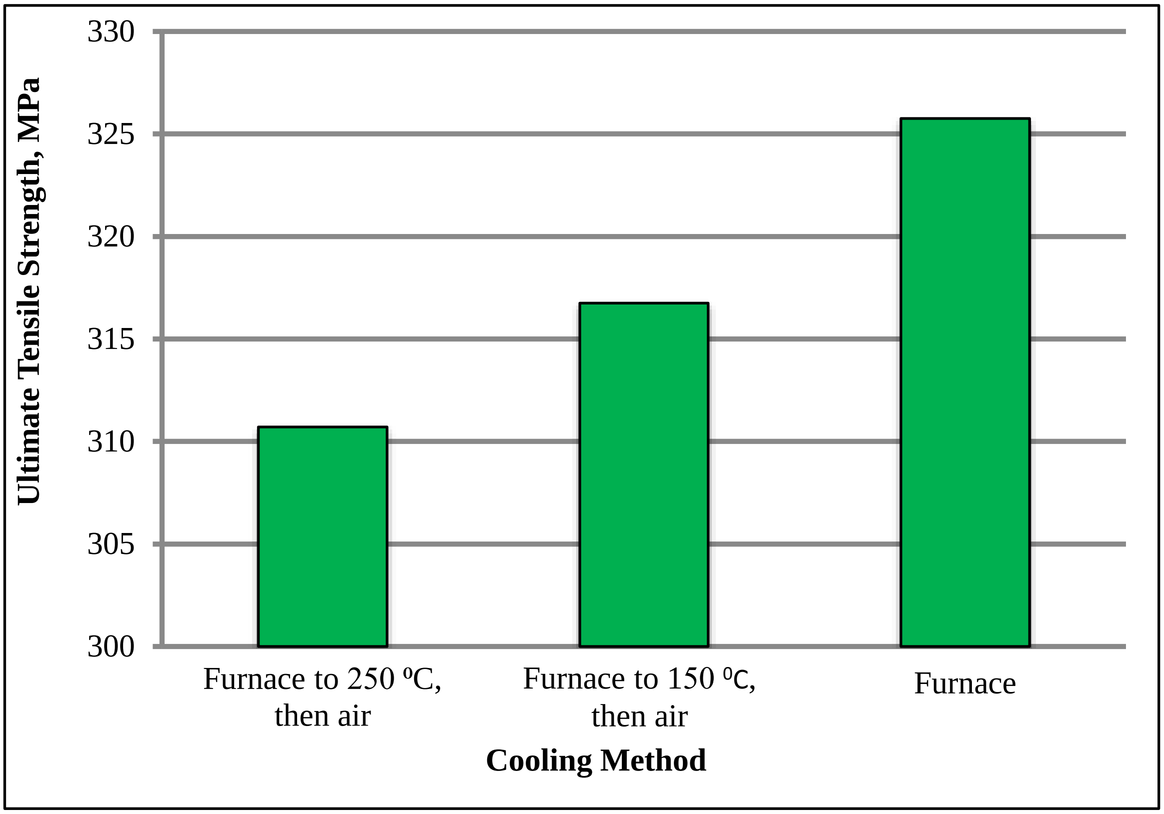

Figure 3. Effect of the cooling method on the ultimate tensile strength for 7075 aluminum alloy

The effect of the cooling method on the modulus of resilience for 7075 aluminum alloy is illustrated in Figure 4. As indicated in Figure 4, the aluminum alloy 7075 which cooled in furnace has high modulus of resilience value followed by the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air but when the aluminum alloy 7075 cooled in furnace to 250 ^{0}C, then air, the modulus of resilience value will be low. Slow cooling in furnace increases the modulus of resilience for the aluminum alloy 7075. The increase in the modulus of resilience may be due to an increment in the yield strength since the modulus of resilience is proportional to the yield strength. It is evident that 7075 aluminum alloy cooled in furnace significantly better than 7075 aluminum alloy cooled in furnace to 250 ^{0}C, then air cooling method and 7075 aluminum alloy cooled in furnace to 150 ^{0}C, then air cooling method.

The relationship between the fracture strength of 7075 aluminum alloy and the cooling method is illustrated in Figure 5. As plotted, the cooling method in furnace gives the highest value of strength (σ_f = 320.5 MPa), and the cooling in furnace to 250 ^{0}C, then air gives the lowest value (σ_f = 305.3 MPa).

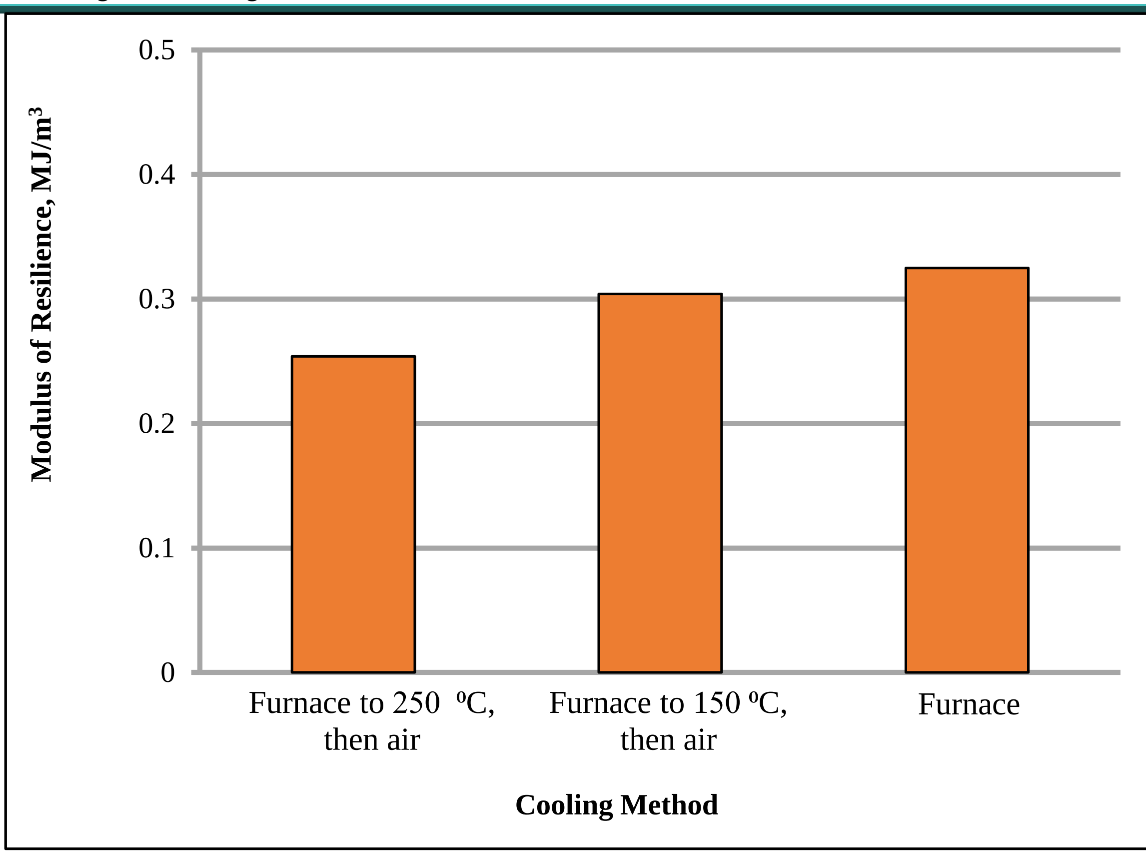

Figure 4. Effect of the cooling method on the modulus of resilience for 7075 aluminum alloy

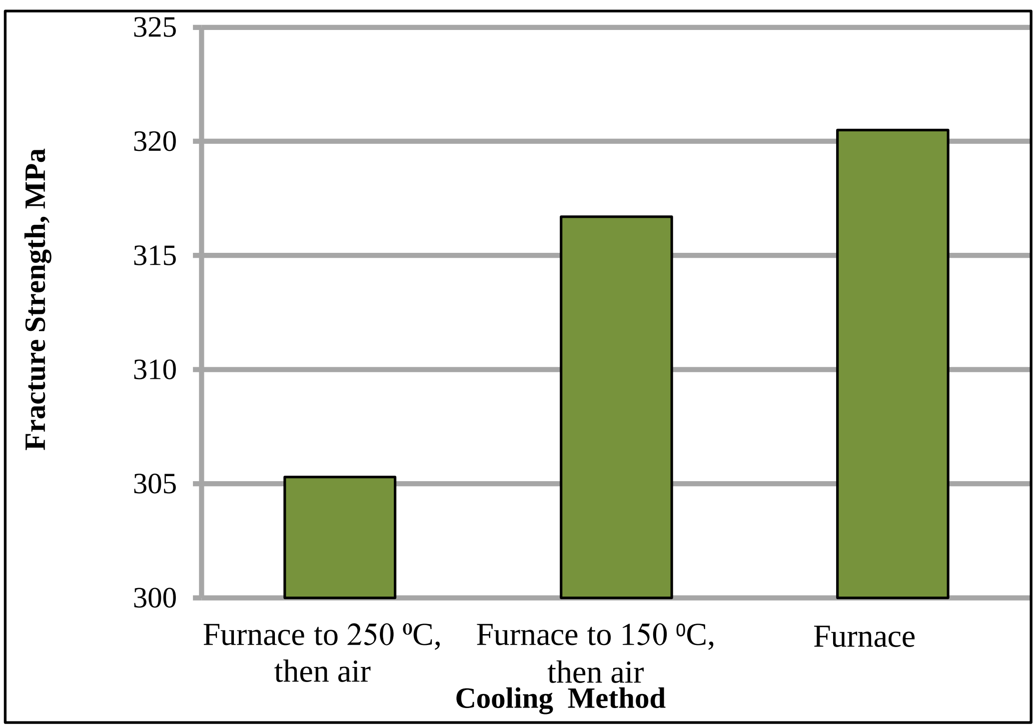

Figure 5. Effect of the cooling method on the fracture strength for 7075 aluminum alloy

In Figure 6, the modulus of toughness for 7075 aluminum alloy and the cooling method is presented. It is well known that the toughness measures the energy required fracturing and modulus of toughness of the material can be related to the area under the stress-strain curve. As indicated in Figure 6 the high modulus of toughness value (47.3 MJ/m^3) is produced by the aluminum alloy 7075 cooled in furnace, followed by the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air, and lastly the aluminum alloy 7075 cooled in furnace to 250 ^{0}C, then air. The reason of increasing the modulus of toughness up to 47.3 MJ/m^3 may be a result of the increase in the ductility as shown in Figure 7.

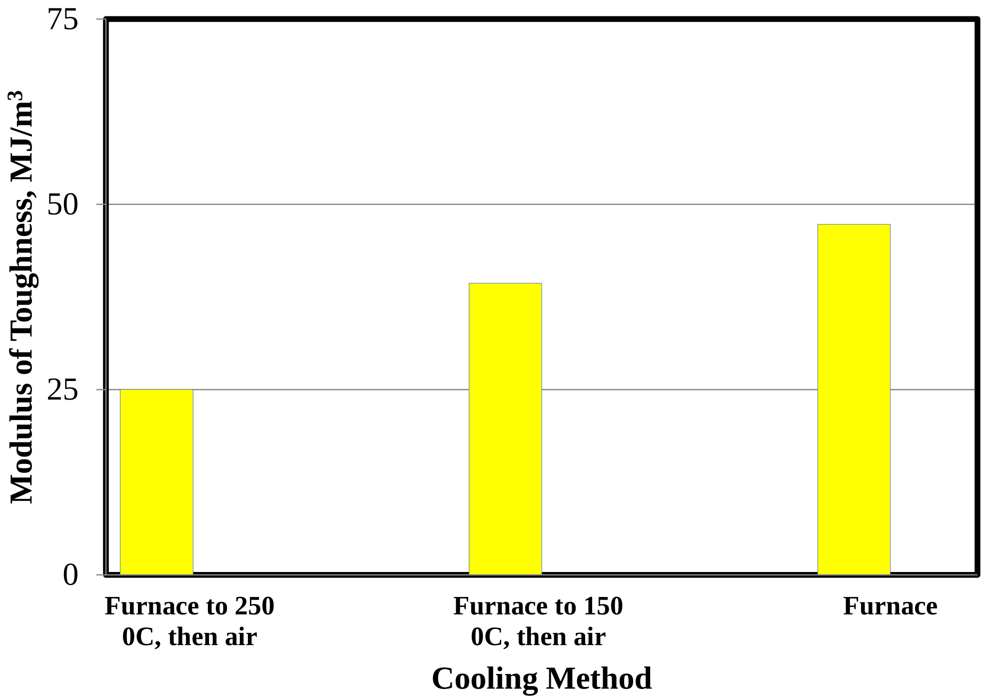

Figure 6. Effect of the cooling method on the modulus of toughness for 7075 aluminum alloy

The ductility as a percent elongation for 7075 aluminum alloy with cooling method is plotted in Figure 7. As it is evident in Figure 7, the ductility depends on the method of cooling. The ductility as a percent elongation can follow this order: the aluminum alloy 7075 cooled in furnace (17.5 %) > the aluminum alloy 7075 cooled in furnace to 150 ^{0}C, then air (15 %) > the aluminum alloy 7075 cooled in furnace to 250 ^{0}C, then air (10 %). This means slow cooling in furnace increases the ductility value of the aluminum alloy 7075. The cooling of the aluminum alloy 7075 in furnace to 250 ^{0}C, then air reduces the ductility value.

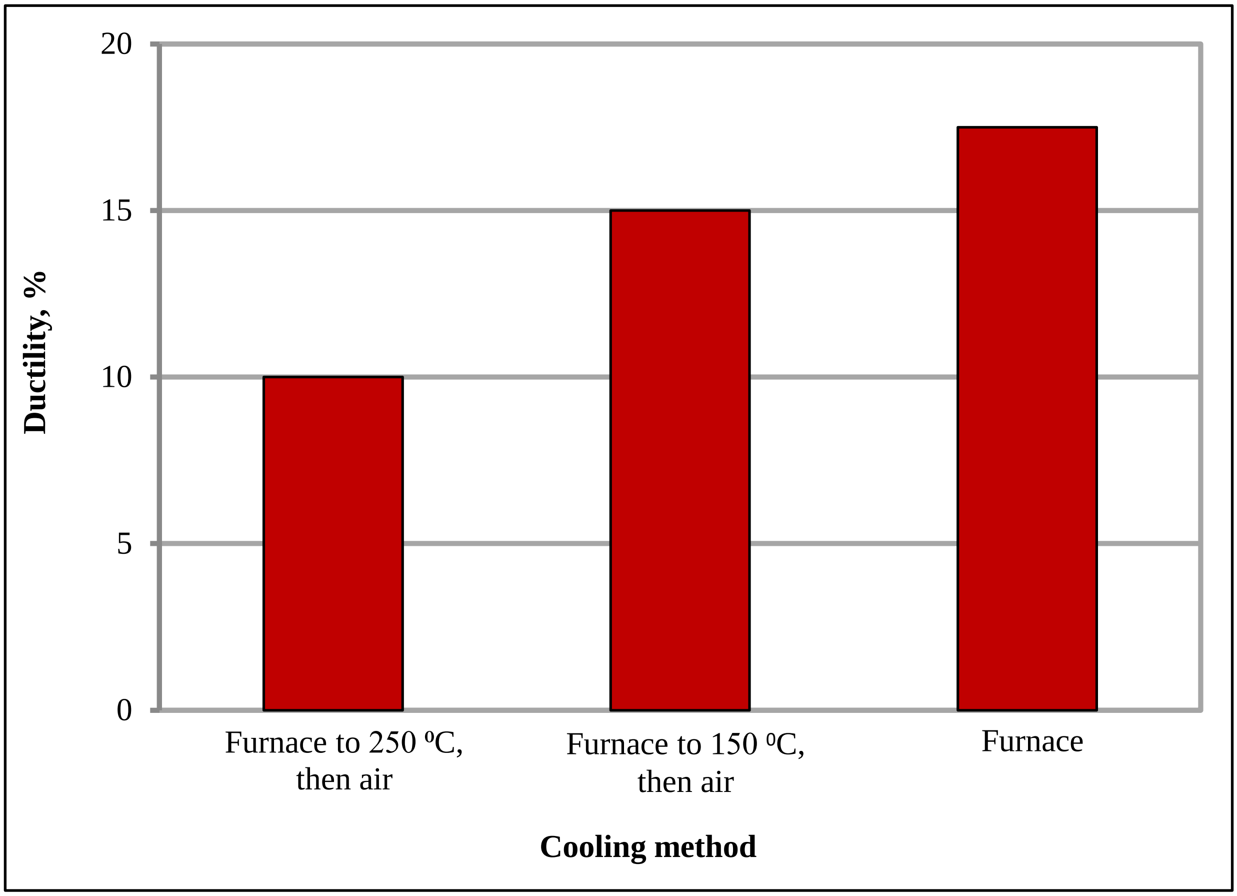

Figure 7. Effect of the cooling method on the ductility as a percent elongation for 7075 aluminum alloy

3.2 FRACTURE SURFACE EXAMINATION

Fracture of metals may generally be classified as either ductile fracture or brittle fracture. Ductile fracture is accompanied by severe plastic deformation prior to failure. On the other hand, brittle fracture shows little or no deformation prior to fracture [12]. Figure 8 shows optical microscope fractography for 7075 aluminum alloy cooled in furnace to 250 ^{0}C, then air, 7075 aluminum alloy cooled in furnace to 150 ^{0}C, then air, and 7075 aluminum alloy cooling in the furnace. From Fig. 8 it can be seen that the fracture surface of the tested specimens have a conical dimples, which are indicative of plastic deformation (i.e. ductile fracture).

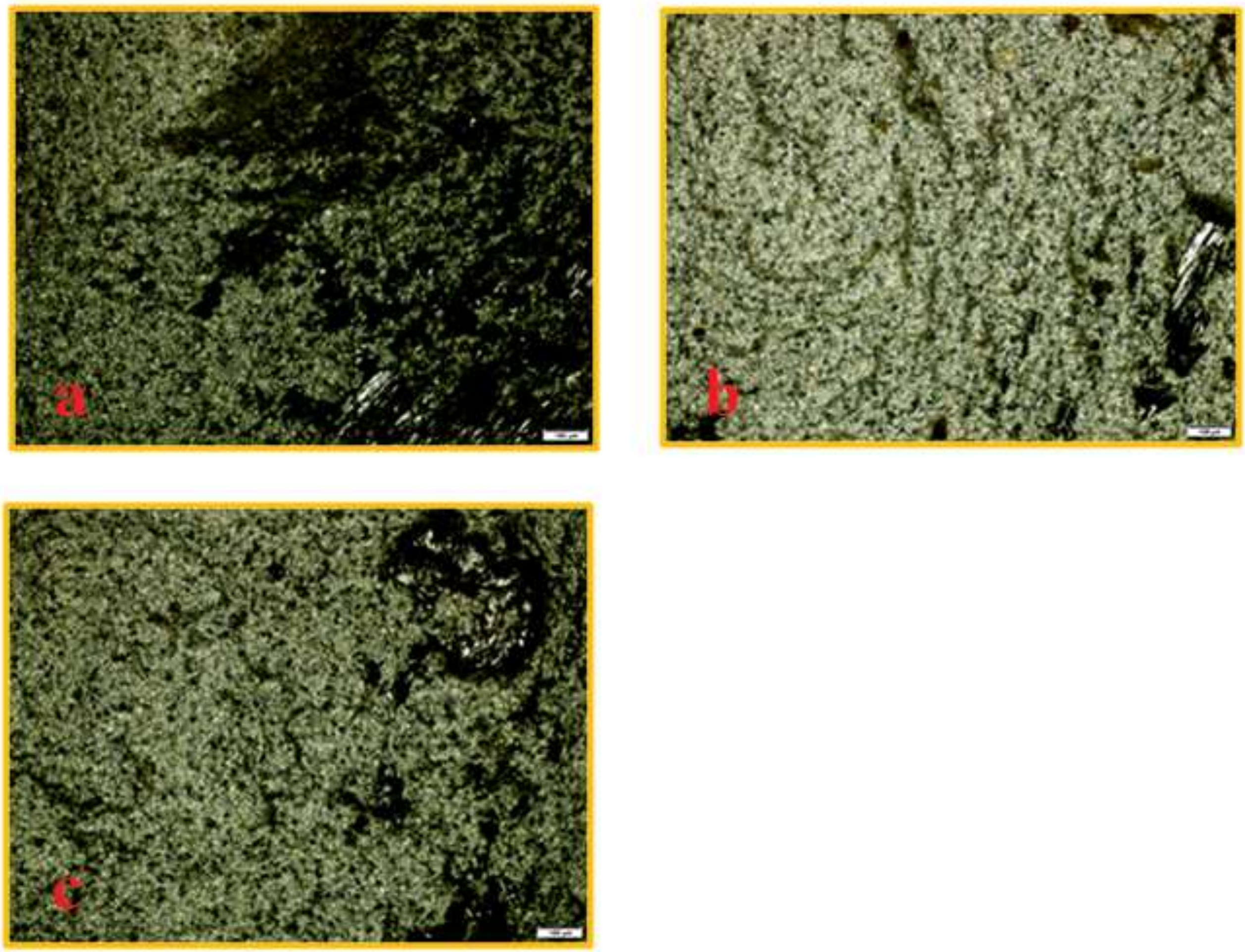

Figure 8. Optical microscope of fracture surface for 7075 aluminum alloy cooled in (a) furnace to 250 ^{0}C, then air; (b) furnace to 150 ^{0}C, then air; and (c) the furnace

4. CONCLUSIONS

Under the conditions of this work, it can be concluded that:

1. Cooling in the furnace gives the highest values of yield strength, ultimate tensile strength, and modulus of resilience, modulus of toughness, ductility and fracture strength for 7075 aluminum alloy.
2. Cooling in the furnace to 250 ^{0}C, then air gives the lowest values of yield strength, ultimate tensile strength, and modulus of resilience, modulus of toughness, ductility and fracture strength for 7075 aluminum alloy.
3. Fracture surface for 7075 aluminum alloy is significantly affected by different cooling methods.

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