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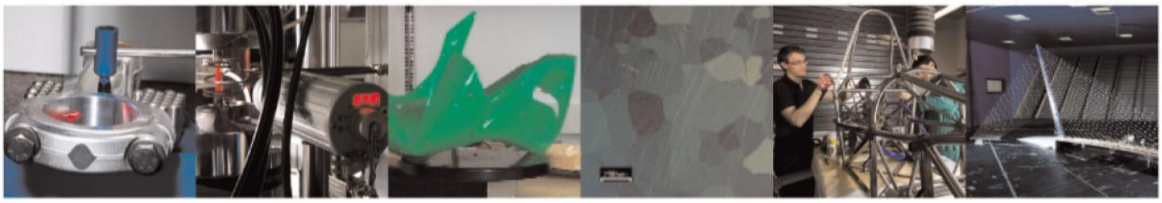

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This is a post-peer-review, pre-copyedit version of an article published in Physics of Metals and Metallography. The final authenticated version is available online at:
http://dx.doi.org/10.1134/S0031918X20140161

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INVESTIGATION OF MECHANICAL PROPERTIES OF AA7075 ALLOYS AGED BY VARIOUS HEAT TREATMENTS

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In this study, annealing (O), artificial aging (T6), retro-regression aging (RRA) and high temperature pre-precipitation (HTPP) heat treatments were applied to AA7075 aluminium alloys. The effects of these treatments on the mechanical properties of AA7075 alloy were investigated. The microstructures of the samples were examined by Optical Microscope (OM), Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX) analysis. Then, X-ray diffraction analysis (XRD) was conducted to identify intermetallics formed in the microstructure of the samples. Tensile and hardness tests were carried out to investigate the mechanical properties. Results showed that secondary phase particles such as Al_2Cu, Al_2CuMg and $MgZn_2$ are formed in the microstructures. In terms of the mechanical properties, T6 applied samples showed the best results. The HTPP applied alloy which presented optimum ductility behaviour among the other heat-treated samples. Dimples and some cleavage surfaces were observed on the fracture surfaces of the samples. Therefore, it is concluded that a ductile/semi-ductile fracture occurred on the samples.

Keywords: Aluminium alloys, Heat treatments, Mechanical properties.

INTRODUCTION

Aluminium alloys are widely used in many sectors such as aerospace, automotive and construction due to their good mechanical and corrosive properties. 7xxx alloys are mostly used for aircraft/automotive parts and mobile equipment applications, where higher strength is required. The alloy contains 1-8% zinc (Zn) as well as copper (Cu), magnesium (Mg), chromium (Cr) and zirconium (Zr) as alloying elements [1, 2]. Different heat treatment methods are applied to these alloys to provide special service properties such as high strength, corrosion resistance and fracture toughness [3, 4]. 7xxx series aluminium alloys can be hardened by aging for high performance structural applications [5]. Aging heat treatment consists of three stages; solution treatment, quenching and aging. In the first stage, the material is held at a high temperature to provide a single phase (α - alpha supersaturated) which is rich in alloying elements. In the second stage, the material is quenched to maintain this supersaturated structure at room temperature. At the last stage, the aging process is performed by holding the alloy at aging temperature for a certain time, depending on the physical properties of the alloy. But one or more of the alloying elements must be completely or highly soluble in the matrix to make the aging mechanism work [6]. Zn and Mg elements are highly soluble in the matrix of 7xxx alloys [7]. With the help of ageing temperature, these elements are forced to push out from supersaturated crystal lattice due to the decreased matrix solubility. Therefore, the atoms are aggregated into small precipitates (secondary phase). [8] This secondary phase precipitation increases the strength of the material by inhibiting dislocation movements [9]. T6 heat treatment is generally preferred to improve strength of 7075 alloys [3]. However, T6 heat treatment also causes weak corrosive properties such as stress corrosion cracking [10-12]. Alternative heat treatment methods such as T73 are developed to improve corrosion resistance, but those treatments mostly affect the mechanical properties negatively [13-15]. Therefore, researchers have developed heat treatment methods such as retro-regression and re-aging (RRA) and high temperature pre-precipitation (HTPP) in order to improve corrosion resistance while trying to maintain strength [16-18].

There are studies focused on the comparison of corrosion and mechanical properties especially hardness, strength and wear. However, there are quite limited studies on the combined effects of T6, RRA and HTTP heat treatments. This study aims to determine the variation of the mechanical behaviour of AA7075 alloys exposed to four different heat treatments.

EXPERIMENTAL

AA7075 alloy was provided from Alkor Casting Alloys Ltd. Company. Chemical composition of the AA7075 alloy was given in Table 1. Before the experimental study, the material was annealed for 2 hours at 500°C. The samples were then machined to the dimensions of standard test methods for tensile testing of metallic materials ASTM-E8M [19]. The heating and cooling rate were kept constant as 10°C/min.

Table 1. Chemical analysis results of AA7075 alloy

Element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti
Comp. [%]	0.17	0.28	1.30	0.15	2.19	5.16	0.19	0.009

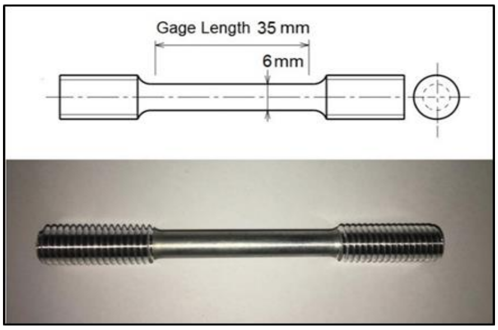

Fig. 1. Tensile test specimen and dimensions .

Heat treatment processes were applied directly to tensile test specimens. First group of specimens were treated by T6 artificial aging heat treatment method. The specimens were solution treated at 485 °C for 2 hours and then quenched in water. This was followed by aging stage of holding the specimens at 120°C for 24 hours. The second group of specimens were first treated by T6, then they were processed by RRA heat treatment method. For RRA treatment, the specimens were solution treated again at 220°C for 1 hour and then quenched in salt-water. After these additional step, re-aging was applied at 120°C for 24 hours to complete RRA process. As for HTPP heat treatment method, a pre-precipitating process was carried out at 450°C for 30 minutes after solution treatment at 485 °C for 2 hours and then the specimens were aged at 120°C for 24 hours. Traditional metallographic sample preparation procedures were followed according to ASTM E3-11 standard [20]. Keller reagent was applied to polished surfaces of samples. Nikon Epiphot 200 optical microscope and Carl Zeiss Ultra Plus Gemini SEM equipped with Bruker X Flash 6/10 EDS (energy dispersive spectroscopy) were used for the microstructural characterization studies. Rigaku Ultima IV X-Ray diffractometer was used to investigate the secondary phases formed in the matrix caused by the heat treatment processes. Shimadzu micro-hardness tester was used for hardness tests. Hardness tests were carried out under 500gf (HV0.5) load and a dwell time of 15 seconds. Mean values of five measurements were taken as the results for each sample. Tensile tests were conducted using Zwick/Roell Z600 tensile testing machine according to ASTM-E8M standard. The dimensions of the tensile specimens were given in Figure 1. Tensile tests were carried at 0,001s^{-1} tensile speed at room temperature. Each test was repeated to ensure experimental accuracy.

RESULTS AND DISCUSSION

Optical images of AA7075 alloys processed by different heat treatment methods, were given in Figure 2. Microstructures of the samples indicate a great volume of micro pores in the microstructure of annealed sample (O). This is because the annealed samples are not exposed to as many additional heating cycles as the other samples. Besides, a considerable part of micro pores is lost by atomic diffusion during solution treatment and ageing. In the AA7075 alloys treated with aging heat treatment, a rough Al-Cu-Mg eutectic or Al-Cu type eutectic phases are observed. This microstructural state is supported by some previous studies [21, 22]. The microstructures of the alloys processed by T6 and HTPP heat treatments are similar to each other. The microstructure of the AA7075 alloy aged with RRA is observed to contain smaller eutectic structures compared to others.

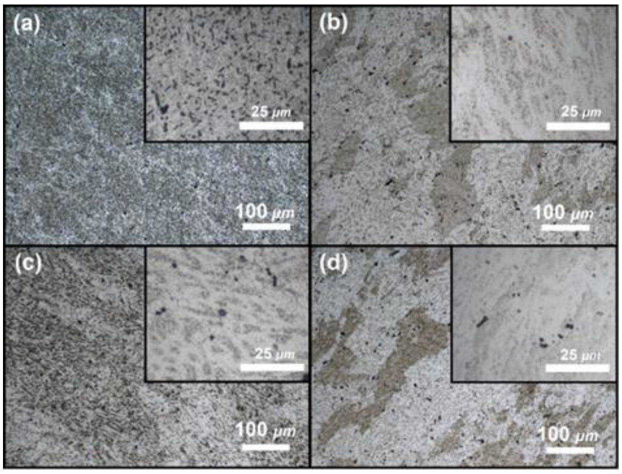

Fig. 2. Optical microscope images of AA7075 alloys aged by different aging heat treatments; (a) O, (b) T6, (c) RRA, (d) HTPP

Figure 3 gives the SEM images of AA7075 alloys treated by different aging heat treatments. Annealed (O) alloys contain great number of micro-pores. It is notable that the microstructures of the alloys treated by T6 and HTTP showed similarities. However, the secondary phases formed in the microstructure of the T6 alloy are relatively more distinct. This is because the second phase precipitates are denser. In previous studies, it is stated that second phase precipitations are formed by the effect of aging and their size and volume ratio are related to aging process parameters [8, 23]

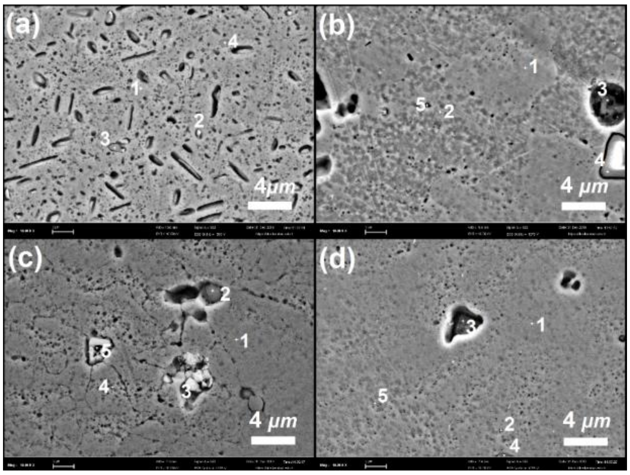

Fig. 3. SEM and EDS analyses of AA7075 alloys aged by different heat treatments; (a) O, (b) T6, (c) RRA, (d) HTPP.

The heat treatment may cause the phase contents change and some intermetallics may also be formed in the microstructure. Therefore, the samples were analysed by XRD analysis to isearch for the possible intermetallic compounds. XRD results given in Figure 4 show phases such as Al_2Cu, Al_2CuMg, $MgZn_2$ in the microstructure as a result of different aging heat treatments (PDF Card No: Al:00-001-1176; Al_2Cu:00-002-1309; Al_2CuMg:00-028-0014; $MgZn_2$:00-034-0457). It is also seen that XRD results exactly correspond to diffraction patterns of AA7075. Recent studies report that stable and/or unstable $MgZn_2$ are formed in the structure of AA7075 alloys [24]. It has also been reported that copper formed intermetallics with aluminium and iron [25]. EDS results obtained from the same samples are given in Table 2 and XRD results support the EDS results. Cu-rich phase regions were formed as Al_2Cu (Table 2.a-P2, c-P3, d-P3) and Al_2CuMg (Table 2.a-P4, b-P1-2, c-P1-2, c-P1). In addition, it can be argued that the $MgZn_2$ phase occurs at the points where the Zn and Mg amounts are high (Table 2.b-P5, c-P4, d-P2). Although there are Fe-rich and Si-rich regions in EDS (point analysis) results, compounds containing these phases could not be detected by XRD analysis. This is due to the small amount of these elements in the chemical composition of the AA7075 alloy (Table 1).

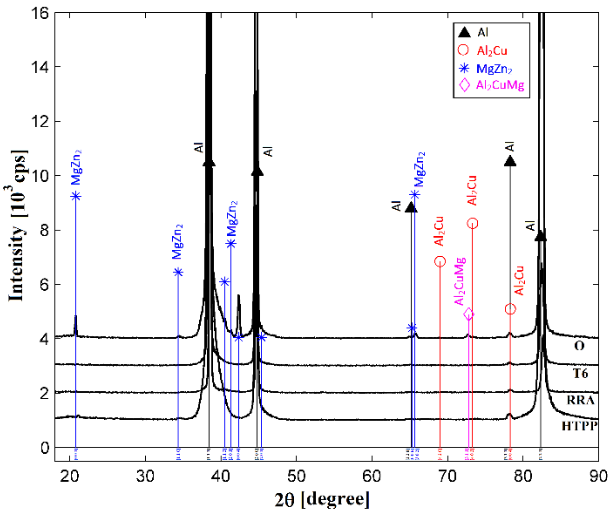

Fig. 4. XRD patterns of AA7075 alloys aged by different heat treatments; From top to bottom: O, T6, RRA, HTPP.

Table 2. EDS (point analysis) results of AA7075 alloys with different aging heat treatments

Figure 3.	Point. (P)	Al	Mg	Zn	Cu	Fe	Mn	Si
(a)	1	91.6	1.6	4.2	2.1	-	0.3	0.1
	2	68.7	1.6	4.0	25.3	-	0.3	-
	3	50.1	1.4	3.0	5.8	0.5	-	38.9
	4	90.2	1.7	3.6	3.7	0.6	-	-
(b)	1	86.2	2.8	7.3	3.1	-	0.4	-
	2	84.5	2.7	7.9	3.8	-	1.1	-
	3	84.6	2.4	6.1	4.1	0.7	1.0	0.9
	4	25.9	1.2	3.2	1.7	-	-	67.9
	5	86.5	2.8	7.2	2.9	-	0.4	-

Table 2. EDS (point analysis) results of AA7075 alloys with different aging heat treatments (Continued)

Figure 3.	Point. (P)	Al	Mg	Zn	Cu	Fe	Mn	Si
(c)	1	83.3	2.7	7.8	4.7	1.3	-	-
	2	84.6	3.0	7.8	3.2	0.9	0.3	-
	3	6.5	0.4	7.1	85.3	-	-	0.5
	4	85.8	2.8	7.9	3.4	-	-	-
(d)	1	85.1	3.1	8.3	3.1	0	0.2	-
	2	84.7	2.7	7.8	2.6	2.0	0.1	-
	3	39.2	0.6	5.1	36.3	18.7	-	-
	4	32.7	1.4	4.2	1.5	0.6	0.4	59.0
	5	85.1	2.7	8.4	3.7	-	-	-

Hardness Test Results;

Figure 5 gives hardness of AA7075 alloys processed by heat treatments. The highest hardness value among the four different treatment methods was obtained in T6 treated alloy as 196 HV. The lowest hardness value was measured as 76 HV in annealed sample (O). The hardness values of RRA and HTPP alloys were measured as 161 and 184 HV, respectively)

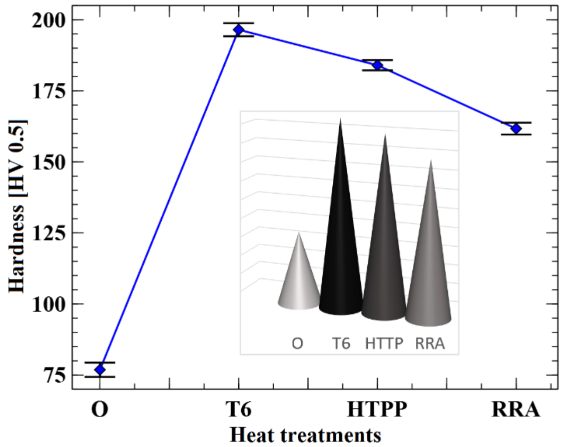

Fig. 5. Hardness values of AA7075 alloys aged by different aging heat treatments.

Aging heat treatments increased the hardness of AA7075 alloy significantly. Hardness results are supported by some studies in the literature [26-28]. Previous studies report that T6 heat treatment greatly increased the hardness of AA7075 alloy, while RRA and HTTP heat treatments are quite close to each other but have a lower effect on the hardness compared to the T6 [29, 30]. The main reason increasing the hardness is known to be the formation of second phase precipitations in the matrix as a result of heat treatment [31]. Aging heat treatment increases hardness because the secondary phase particles prevent the dislocation movement. T6 alloy has higher hardness compared to other heat-treated alloys because the precipitations exhibit a continuous distribution at the grain boundaries [12]. The decrease in the hardness of the alloys where RRA and HTPP heat treatments were applied, can be due to increasing size and decreasing density of the secondary phase precipitates as a result of the extended heat treatment duration. Re-solution and re-aging processes cause a decrease in hardness, and this is also described as over-aging [27]. In addition, it is known that the size of the second phase precipitations affect the hardness [11, 25, 32].

Tensile Test Results;

Stress-strain curves obtained from the tensile tests were given in Figure 6. Comparing the annealed alloy with other alloys, the results seem to be similar with the hardness results given in Figure 5. Comparable to the hardness results, it was seen that approximately two times higher tensile strength is obtained from T6 and HTPP heat-treated samples. In addition, the best results of ductility were observed in annealed samples. These results are also related to the coarse-grained structure of annealed samples [33].

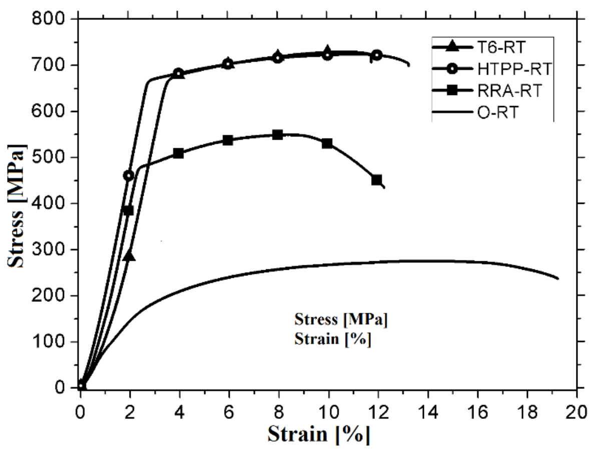

Fig. 6. Mechanical properties of AA7075 alloys aged by different heat treatments; Tensile stress and strain curves.

As for the tensile properties, annealed alloys showed the lowest tensile properties with 183.5 MPa yield stress, 274.3 MPa tensile stress and 6.7 GPa modulus of elasticity. On the other hand, the highest tensile properties were obtained from T6 alloys with 698.5 MPa yield strength, 729.3 MPa tensile strength and 28.1 GPa modulus of elasticity. RRA applied alloys had 493.2 MPa yield strength, 548.6 MPa tensile strength and 27.7 GPa elastic modulus values. And HTPP applied samples had 688.9 MPa yield strength, 720.3 MPa tensile strength and 29 GPa elastic modulus values. According to the results T6 and HTPP alloys showed better tensile strength properties compared to the RRA alloy. Yield stress and elastic modulus of the alloys processed by different heat treatment methods were given in Figure 7. According to the results, the yield strength of T6 and HTPP alloys were higher than that of RRA alloys. The most important reason for lower strength can be repetitive heating cycle of RRA heat treatment. Therefore, the second phase precipitations formed in the structure grow due to over-ageing [11].

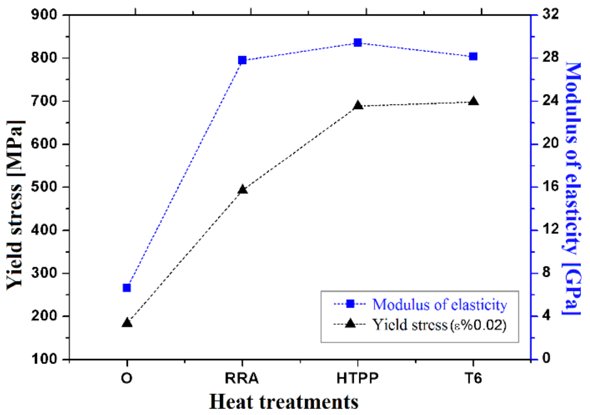

Fig. 7. Yield stress and modulus of elasticity values of AA7075 alloys aged with different heat treatments.

The fracture surfaces were analysed by SEM and the resulting images were given in Figure 8. It was observed that the dimple formation is dominant on fracture surfaces examined after the tensile tests. On the other hand, cleavage planes and protrusions were also seen. It was seen that alloys exhibit a ductile/semi-ductile fracture behaviour. The fracture surface results show similarities with the broken surfaces of AA7075 alloys in the literature. [34-36]. Both types of fracture mechanisms that tend to be brittle and ductile, can be observed in different regions in some studies. This was associated with various thermal and mechanical process conditions [37, 38] Mixed fracture containing dimple and quasi-cleavage fracture can also be seen [39]. The morphologies of dimples on the fracture surfaces of HTPP alloy were changed, and accordingly the structure showed more ductile behaviour. Fracture may differ depending on the second phase particle shape, volume ratio, and the state of the matrix and particle interface. In a previous study, it was reported that quasi-cleavage regions containing many dimples occur in the fracture surfaces of over-aged samples in Al-Zn-Mg alloys [34]. Breaking of secondary phase particles plays an important role in the formation of gaps in the particle-matrix interface [40].

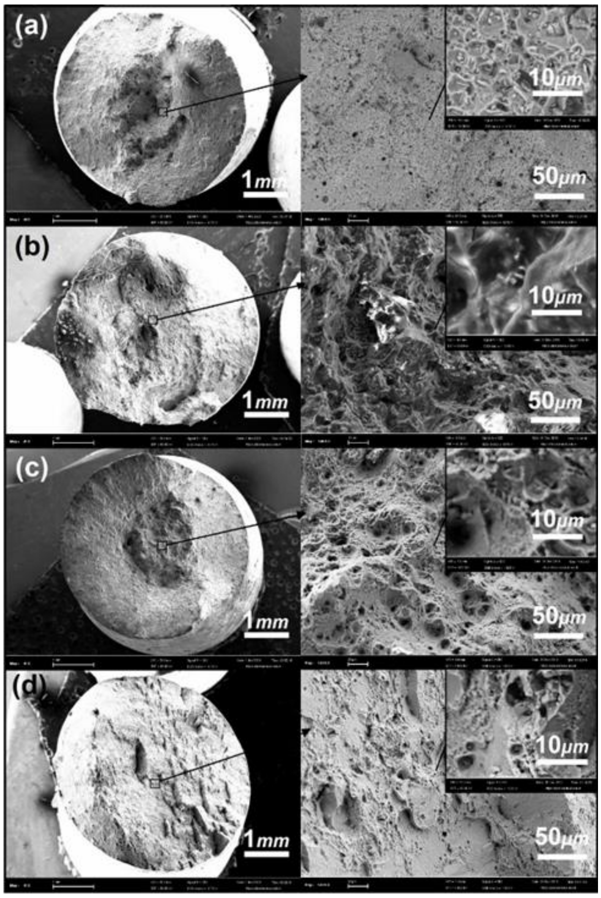

Fig. 8. SEM fractographies of the tested specimens aged by different heat treatments; (a) O, (b) T6, (c) RRA, (d) HTPP.

CONCLUSIONS

In this study, AA7075 alloy was exposed to different heat treatment conditions. The effects of different heat treatment methods on microstructure and tensile properties were investigated. As a result of heat treatments, Al_2Cu, Al_2CuMg and $MgZn_2$ secondary phases were observed in the microstructure. Microstructures are directly affected by heat treatments applied. Tensile and hardness results vary according to heat treatment conditions. The highest hardness value was measured in T6 alloy, while the lowest hardness value was found in the annealed alloy. It can be concluded that the most durable material in terms of yield stress and elastic properties was T6 alloy. It has been determined that AA7075 alloys with heat treatments have lower ductility properties than annealed alloy. As for the elongation values, it was seen that the materials applied HTPP exhibit more ductile behaviours than the T6 applied alloys. Fracture surfaces of the samples indicate that the dimple regions were predominant. A ductile/semi-ductile fracture with cleavage surface and ledges were observed.

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