Chapter 1

Influence of T6 heat Treatment on the Mechanical Properties of AA7075 and AA7020 alloys

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Abstract

The AA7075 and AA7020 alloys were prepared using a vacuum melting furnace and a casting furnace. Mechanical properties of the alloy samples were investigated as-cast and under heat-treated conditions. To investigate the effect of heat treatment, numerous designed AA7075 and AA7020 samples were homogenized (solution process) in two steps (300 °C/12h+475 °C/12h) and then aged under different regimes. The mechanical properties of microhardness (HV), ultimate tensile strength (σ_{UTS}), tensile yield strength (σ_{TYS}), compressive yield strength (σ_{CYS}) and Young's modulus (E) were measured to investigate the effect of heat treatment on mechanical properties. Both alloy systems (AA7075 and AA7020) were compared both within themselves and with each other in terms of mechanical properties depending on how they were subjected to the heat treatment. Depending on the applied heat treatments, 7075 alloy exhibited superior mechanical properties

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compared to 7020 alloy. A good combination of high microhardness and reasonable tensile strength has been achieved for both alloy systems by sequential and appropriate heat treatment. While the peak σ_{UTS} value reached for the AA7075 alloy was 425 MPa (regime 3), it was determined as 320 MPa (regime 2) for the AA7020 alloy. After the aging process at 150 ^{o}C/24h (regime 2) applied proceeding the homogenization process, the peak HV and σ_{CYS} values for AA7020 alloy were achieved as 1235 MPa and 321.6 MPa, respectively.

1. INTRODUCTION

Due to its high strength/weight ratio and shapeability, Aluminum is used in a wide range of areas from construction applications to structural parts of various vehicles (automobile bodies, engine parts, aircraft bodies, etc.). Due to the low densities of these alloys, besides the energy efficiency they provide, they are preferred in terms of sustainability, which has been emphasized in recent years, as well as their easy recycling properties. Nowadays, intensive studies on alloy properties, heat treatment and forming technologies are carried out in order to increase the existing properties of aluminum. 7xxx alloys are considered to be the most important group among heat treatable aluminum alloys. Depending on the applied heat treatment, there are great increases in mechanical properties (Hatch, 1984). In applications requiring high strength, 7xxx series aluminum alloys, which can be hardened by aging, are preferred (Rometsch, Zhang & Knight, 2014).

The increase in the mechanical properties of the alloy with aging is due to the difficulty of the dislocation movement of the secondary phase precipitates formed by heat treatment in the structure (Tekeli *et al.*, 2019). Aging is a three-stage heat treatment. These consist of solution, quenching and aging stages. In the solution stage, the material is kept at high temperature in order to obtain a supersaturated, single-phase solid-solution rich in alloying elements. In the quenching phase, the material is cooled rapidly and the supersaturated microstructure is preserved at room temperature. In the aging stage, the rapidly cooled alloy is kept at a certain aging temperature for a certain period of time, and the second phase is formed in the structure.

The effects of the heat treatment on the mechanical properties (microhardness, ultimate tensile strength, compressive strength) of the AA7075 (Al-5.5Zn-2.5Mg-1.5Cu wt.%) and AA7020 (Al-4.5Zn-1.2Mg-0.15Cr-0.15Zr wt.%) alloys have not been investigated in a comparative manner. Therefore, the purpose of the present work was to investigate mechanical properties of the AA7075 and AA7020 alloys depending on the heat treatment.

2. EXPERIMENTAL PROCEDURES

2.1. Preparation of the AA7075 and AA7020 cast alloys

Weighed quantities of high purity (99.99 %) Al, Zn, Mg, Cu and other minority metals (Cr, Zr) were used to prepare the AA7075 and AA7020 cast alloys (all compositions are given in wt.% unless otherwise noted). First, Al was placed in a graphite crucible (L:170 mm, OD: 40 mm, ID:30 mm) and melted in a vacuum furnace. After complete melting of Al, the required amount of Zn was placed under the surface of the liquid Al. Three stirrings of the liquid Al-Zn alloy were carried out at five-minute intervals, and then required amount of Mg packed with pure thin Al foil was placed in a graphite cage with many perforations; it was then put under the surface of the liquid Al-Zn alloy in order to avoid Mg burning on the surface of the melt. Finally, Cu and other minority metals (Cr and Zr) required according to the type of alloy were put into the crucible and melted. To get homogeneous cast alloys, the alloys were melted again in the vacuum melting furnace by inverting the billet. After stirrings and allowing time for the melt homogenization, the molten alloys were poured through a funnel into a graphite crucible that was connected with other alumina molds (180 mm in length, 9 mm OD, 6 mm ID) placed in a casting furnace. The furnace had lower and upper heaters at temperatures of approximately 50 ^{o}C and 100 ^{o}C above the melting point of the alloy, respectively. Each sample was stirred with a fine alumina rod and then solidified from bottom to top using a water cold stainless-steel reservoir in order to obtain a complete mixture and directionally solidified homogeneous sample. The average cooling rates through the directionally solidified samples were between 8-2 K/s depending on the position relative to the reservoir. The sample preparation experiments were repeated until the necessary numbers of suitable samples were produced. The upper and lower parts (10 mm) of the sample, which may contain casting defects, were discarded and not used for mechanical testing. The remaining parts of the samples for both alloys were prepared for mechanical tests.

2.2. Heat treatment

First, required amounts of samples (for microhardness, tensile and compressive strength tests) were produced for each alloy (AA7075 and AA7020). The solution treatment (homogenization) and aging processes in different regimes applied within the scope of this study are shown schematically in Fig. 1. To compare alloy samples to be heat treated with samples in as-cast form (Fig. 1a), five of the as-cast (without heat treated, WHT) samples group were not exposed to any heat treatment (HT) and they were stored at a low temperature (-18 ^{o}C) in a freezer in order to avoid the natural aging of the alloy at room temperature (RT) for microstructure and mechanical tests. The remaining twenty-five samples were exposed to a two-step 300 °C/12h+475 °C/12h solution treatment process (homogenization) and then quenched in water at RT (Fig. 1b). After the solution treatment process, these twenty-five samples were divided into five subgroups. One of these subgroups was preserved as an only homogenized group. In other words, it was not exposed to any aging treatment process. The remaining four subgroups (five samples in each subgroup) were exposed to artificially aging process (T6) in different conditions (regime1- regime4) (Fig. 1c-f). As shown in Fig. 1, five test samples were allocated for each subgroup to increase the reliability of the data.

The solution heat treatments (T6) were conducted in a Protherm PLF 110/45 model muffle furnace. In the two-step solution process, the samples were first kept at 300 °C for 12 hours and then at 475 °C for 12 hours and then quenched in water at room temperature to obtain a supersaturated solid solution α–Al. Then, the process was completed by performing an artificial aging process in four different regimes. As can be seen from Figure 1c-f, regime 1(120 °C/24h) and regime 2 (150 °C/24h) one step regime 3 (120 °C/12h +150 °C/12h) and regime 4 (150 °C/12h +180 °C/12h) consist of two-step heat treatments. The heat treatment (HT) conditions in both solution treatment and aging process are given in Table 1. After the heat treatments, standard metallography, microhardness, tensile strength, and compressive strength were carried out for all the samples (as-cast (WHT), only homogenized and homogenized+aged samples).

Table 1. Heat treatment processes of theAA7075 and AA7020 alloys

Name of sample	Process	Status
WHT	Without heat treatment	As-cast
OH	Only Homogenization	300 °C/12h+475 °C/12h (two-step)
Regime 1	H+artificial aging	300 °C/12h+475 °C/12h→120°C/24h (one-step)
Regime 2	H+artificial aging	300 °C/12h+475 °C/12h→150°C/24h (one-step)
Regime 3	H+artificial aging	300 °C/12h+475 °C/12h→120 °C/12h+150 °C/12h (two-step)
Regime 4	H+artificial aging	300 °C/12h+475 °C/12h→150 °C/12h+180 °C/12h (two-step)

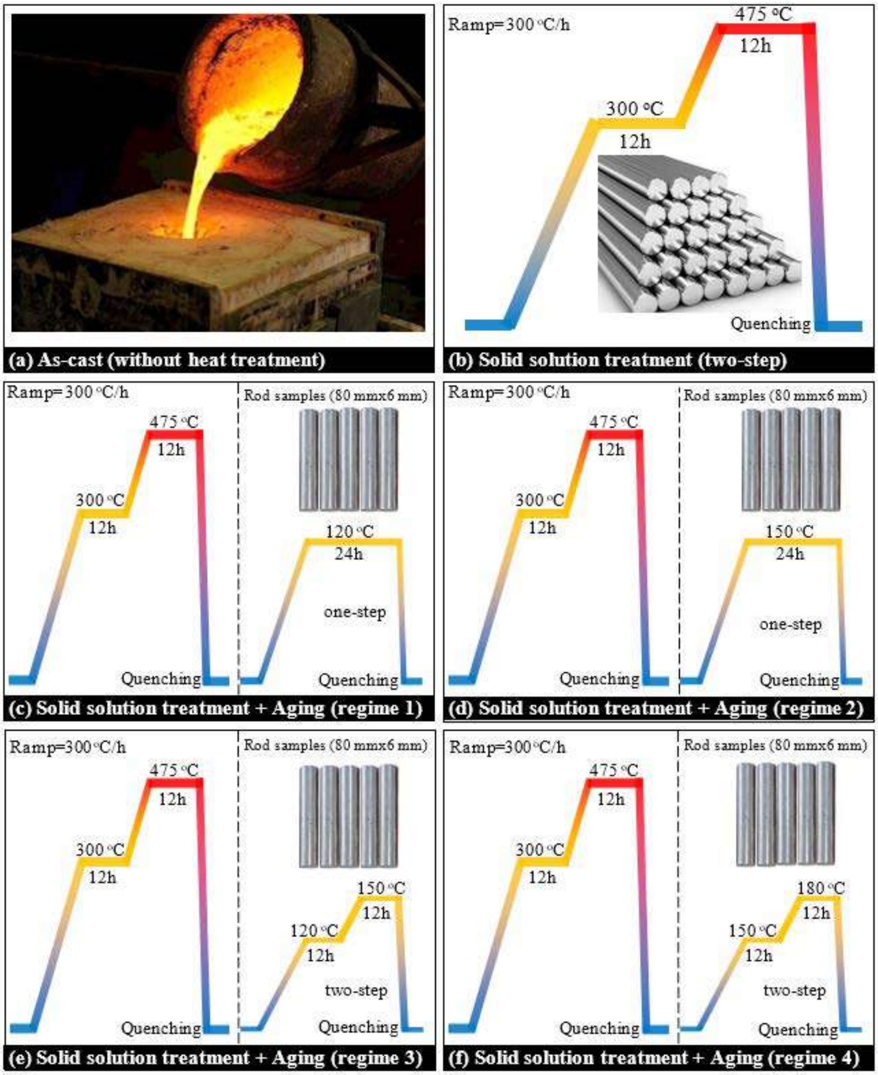


Figure 1. Types of heat treatment process (a) as-cast (without heat treatment WHT) (b) Solution treatment process (300°C/12h+475°C/12h homogenization with two-step) (c) aging regime 1 with one-step (120 °C/24h) (d) aging regime 2 with one-step (150 °C/24h) (e) aging regime 3 with two-step (120 °C/12h +150 °C/12h) (f) aging regime 4 with two-step (150 °C/12h +180 °C/12h)

2.3. Measurement of the microhardness (HV)

Microhardness measurements were conducted at room temperature using a Future-Tech FM−700 model microhardness test apparatus. A 300-gram load was applied to the sample surface for 10 seconds, and approximately 20-25 readings were taken for each section. The mean values were obtained from the microhardness readings. Even though the measurement process was conducted with utmost care, some errors may have occurred due to surface quality of the sample, phase distribution in the microstructure and uncertainty in the traces. Additionally, a measurement error could be caused by the inability to achieve the required sharpness when measuring the diagonal lengths of the trace developed on the sample surface. The percentage of error obtained in the hardness measurements is acceptable (6%) and is within the systematic measurement error limits of the device.

2.4. Measurement of ultimate tensile strength (σ_{UTS}), tensile yield strength ($\sigma_{TYS)}$, and compressive yield strength (σ_{CYS})

The tensile and compressive strength of the samples were evaluated using a Shimadzu AG-XD testing system. The cylindrical samples for tensile testing had a diameter of 6 mm and a length of 60 mm, while the compressive samples had a diameter of 6 mm and a length of 8 mm. For each test, the strain rate for tensile testing was set to 10^{-3} s^{-1} at room temperature and the deformation rate for compressive testing was 1 mm/min. In order to assure the accuracy of the results, the tests were performed three times and the mean values were taken. It was observed that the error of the measurements was around 5%.

3. RESULTS AND DISCUSSION

3.1. Microhardness

Figure 2 shows the effect of various heat treatments on the microhardness values of AA7075 and AA7020 samples. HV values of the as-cast AA7075 and AA7020 samples without heat treatment are found to be 1835 and 350 MPa, respectively. The highest HV value for AA7075 alloy was obtained as 1920 MPa, for the only homogenized sample (300°C/12h+475°C/12h). This value (1920 MPa) is considerably higher than 1235 MPa, which is the highest value obtained for AA7020 alloy (regime 2). Heat treatments led to a greater increase in microhardness values for the AA7020 alloy. The microhardness of the cast sample increased from 350 MPa to 1235 MPa with the heat treatment called regime 2 (H+150 °C/24h). Results obtained for AA7075 alloy were in agreement with some previous studies in which the peak aged conditions of AA7075 alloy formed by squeeze casting and by extrusion were obtained after aging for 24 h at 120 °C (Kim *et al.*, 2001) and for 48 h at 120 ◦C (Emani *et al.*, 2009), respectively. Maamar (Maamar *et al.*, 2008) reported that the microhardness value for an AA7075 alloy increased from 1450 to 1850 MPa after applying the aging treatment. By comparing these microhardness values with our microhardness values, it becomes obvious that aging treatment is successful.

3.2. Tensile strength

Figure 3 shows the strength-strain curves of AA7075 and AA7020 alloys (σ_{TYS} and σ_{UTS} points indicated by yellow dot and black dot, respectively). While the samples of AA7075 alloy showed higher tensile strength compared to the samples of AA7020 alloy, the samples of AA7020 alloy reached higher values in terms of ductility. The elongation in the samples of AA7075 alloy varies between 1.1% and 6.6%, and the highest elongation value was obtained in the sample aged with regime 4. It has been determined that the elongation values obtained in the samples of AA7020 alloy are higher than the samples of AA7075 alloy. The elongation values for the samples of AA7020 alloy ranged between 5.1% and 19.6%, and the highest elongation value was obtained in the sample aged with regime 3.

Figure 2. The influence of homogenization and aging treatment on the microhardness for each alloy

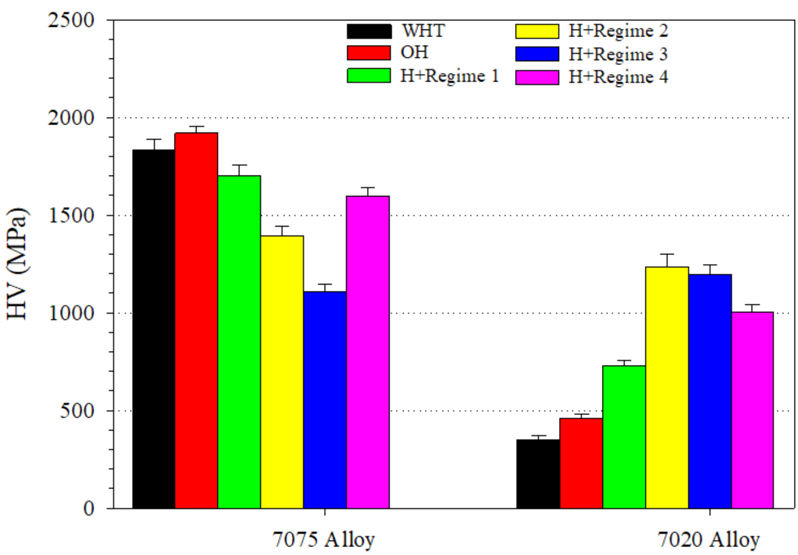
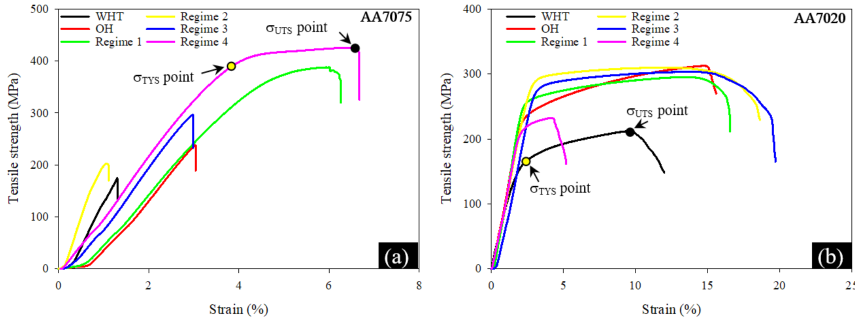


Figure 3. Typical tensile strength-strain curves of the WHT and HT samples (a) AA7075 alloy (b) AA7020 alloy



In Fig. 4a, the ultimate tensile strengths (σ_{UTS}) of the samples AA7075 and AA7020 obtained from the curves in Fig. 3 are given. The lowest σ_{UTS} value for the AA7075 alloy was determined as 174.6 MPa for the WHT sample, while the highest σ_{UTS} value was determined as 425.1 MPa for aged sample with regime 4. Peak σ_{UTS} value was obtained as 328 MPa for this aging process (regime 4) and 243% improvement was achieved compared to the σ_{UTS} value of the as-cast sample (WHT). The lowest σ_{UTS} value for AA7020 alloy was obtained as 212.1 MPa for the WHT sample, while the highest σ_{UTS} value was determined as 312.5 MPa for the only homogenized sample (OH). The σ_{UTS} value (425.1MPa) obtained for the AA7075 alloy is considerably higher than the σ_{UTS} value (312.5 MPa) obtained for the AA7020 alloy.

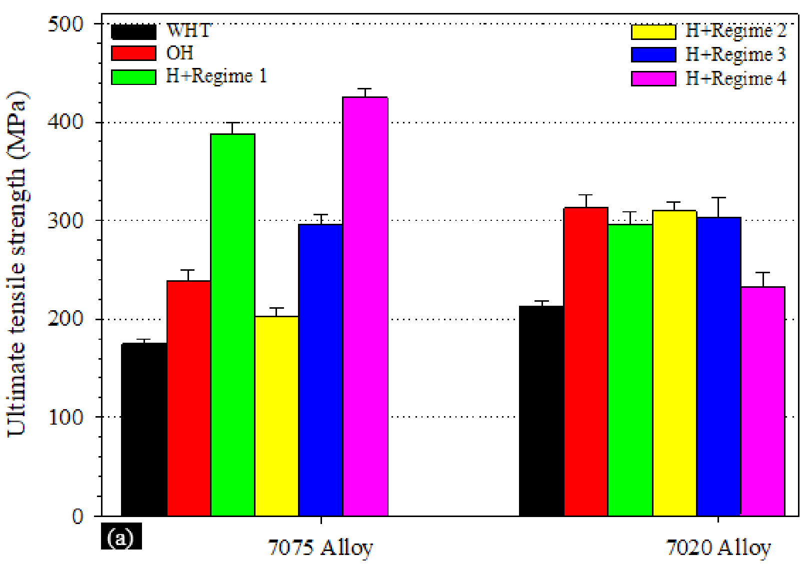
The yield point is the point on a strength-strain curve that indicates the limit of elastic behavior and the beginning of plastic behavior. The tensile yield strength ($\sigma_{TYS)}$ values are shown in Fig. 4b for both alloys. As can be seen in Fig. 4b, while the lowest σ_{TYS} value as 160.1 MPa was determined in the as-cast sample (WHT) without any heat treatment for the AA7075 alloy, the highest σ_{TYS} value as 378.2 MPa was in the aged sample with regime 4. Depending on the applied heat treatments in AA7075 alloy, the change in the σ_{TYS} values shows parallelism with the change in the σ_{UTS} values. In AA7020 alloy, while the lowest σ_{TYS} value as 163.3 MPa was determined in the as-cast sample (WHT) without any heat treatment for the AA7075 alloy, the highest σ_{TYS} value as 293.5 MPa was in the aged sample with regime 2. As can be seen Fig. 4(a-b), the observed parallelism between σ_{TYS} and σ_{UTS}, depending on the heat treatment conditions for the AA7075 alloy, was not observed in the AA7020 alloy. In addition, the highest σ_{TYS} value (378.2 MPa) determined for AA7075 is considerably higher than the highest σ_{TYS} value (293.5 MPa) obtained for AA7020 alloy.

In both alloys, both the σ_{UTS} and σ_{TYS} values improved significantly with aging at different regimes. Similar behaviors on the tensile properties were reported by Mahathaninwong et al. for AA7075 Al alloy (Mahathaninwong *et al.*, 2012), Paulisch *et al.* for AA7020 Al alloy (Paulisch *et al.*, 2015), and Chemingui *et al.* for AA7020 Al alloy (Chemingui *et al.*, 2010). The strengthening mechanism of the aging at T6 for the studied alloy is attributed to the precipitation hardening. In some studies, it is emphasized that the formation of the precipitate is caused by dislocation movement (Chemingui *et al.*, 2010; Chen *et al.*, 2012; Li *et al.*, 2006).

3.3. Compressive strength

Compressive strength-strain curves for AA7075 and AA7020 samples are shown in Fig. 5. Compressive yield strength values were determined from strength-strain curves (σ_{CYS} point indicated by black dot). The values of the σ_{CYS} under different heat treatment processes are shown in Fig. 6. While the lowest σ_{CYS} value was determined as 278.2 MPa for the as-cast sample (WHT) in AA7075 alloy, the highest σ_{CYS} value was determined as 501.6 MPa for the sample aged with the regime 3.

Figure 4. The influence of homogenization and aging treatment on the ultimate tensile strength and tensile yield strength for AA7075 and AA7020 alloys (a) ultimate tensile strength (b) tensile yield strength



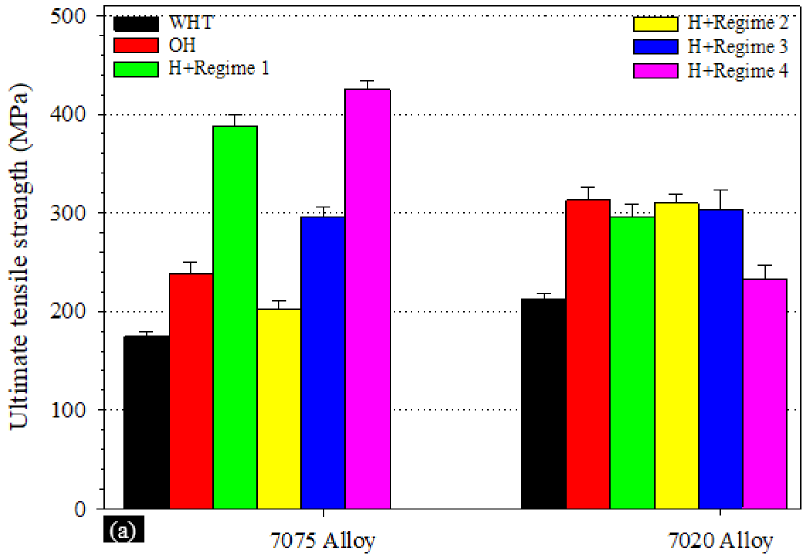
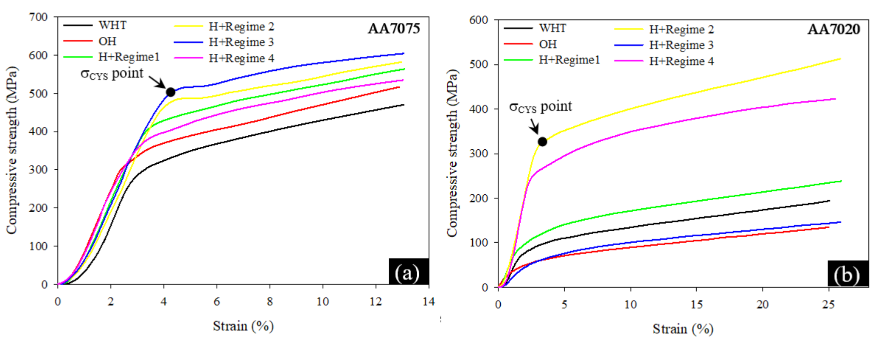


Figure 5. Typical compressive strength-strain curves of the WHT and HT samples (a) AA7075 alloy (b) AA7020 alloy



In AA7020 alloy, on the other hand, the σ_{CYS} values (56.6 and 54.1 MPa) obtained in some regimes (OH, regime 3) were below the σ_{CYS} value (84.7 MPa) obtained for the as-cast sample. However, the highest σ_{CYS} value was obtained as 321.6 MPa in the sample aged with the regime 2. When AA7075 and AA7020 alloys were compared, the highest σ_{CYS} value was found to be 501.6 MPa in the sample aged with the regime 3 in AA7075 alloy, while the highest σ_{CYS} value was found as 321.6 MPa in the sample aged with the regime 2 in AA7020 alloy. Thus, in AA7020 alloy, one-step regime

2 emerged as the most optimum HT process in terms of compressive yield strength, while in AA7075 alloy, the most optimum HT process was determined as two-step regime 3. Peak value (321.6 MPa) of σ_{CYS} obtained for AA7020 alloy in this study (H+regime 2) is in very good agreement with values 310 MPa, 300 MPa and 331 MPa obtained by Feng et al. (Feng *et al.*, 2013) at 190 °C/12h aging process after solution treatment (500 °C/3h) for Al-4Cu-1.3Mg alloy, Samuel *et al.* (Samuel *et al.*, 2015) at 200 °C/5h aging process after solution treatment (495 °C/8h) for 220 Al-2Cu based alloy and Zhan et al. (Zhan *et al.*, 2018) at 160 °C/12h aging process for Al-4.26Cu-1.36Mg alloy, respectively.

3.4. Young modulus

Young modulus values (E) defined from strength-strain curves in Fig. 3 is given in Fig. 7. As can be seen in Figure 7, the E values obtained for both AA7075 and AA7020 alloys vary between 68.6-76.3 GPa. Young's modulus values did not show a radical change depending on the applied heat treatments. While the highest E value was determined as 75.6 GPa for AA7075 alloy (OH), the highest E value was determined as 76.3 GPa for AA7020 alloy (regime 1). In summary the peak values of the mechanical properties detected after HT are given in Table 2. Many heat treatments are used in the metal fabrication and processing industry. Considering these studies, there are many factors that affect the heat treatment processes applied after solidification such as microstructure (size, shape and composition of the different constituent phases), presence of precipitates (composition, distribution, size of the particles), and interactions between dislocations.

Figure 6. The influence of homogenization and aging treatment on the compressive yield strength for AA7075 and AA7020 alloys

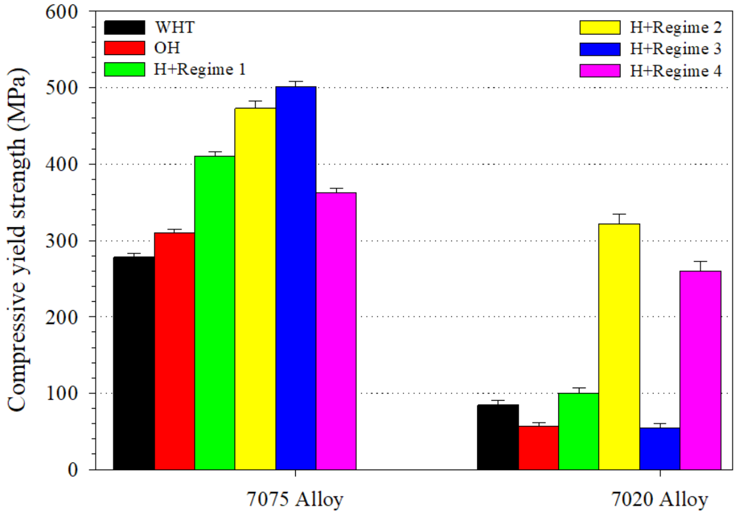


Figure 7. The influence of homogenization and aging treatment on the Young modulus for AA7075 and AA7020 alloys

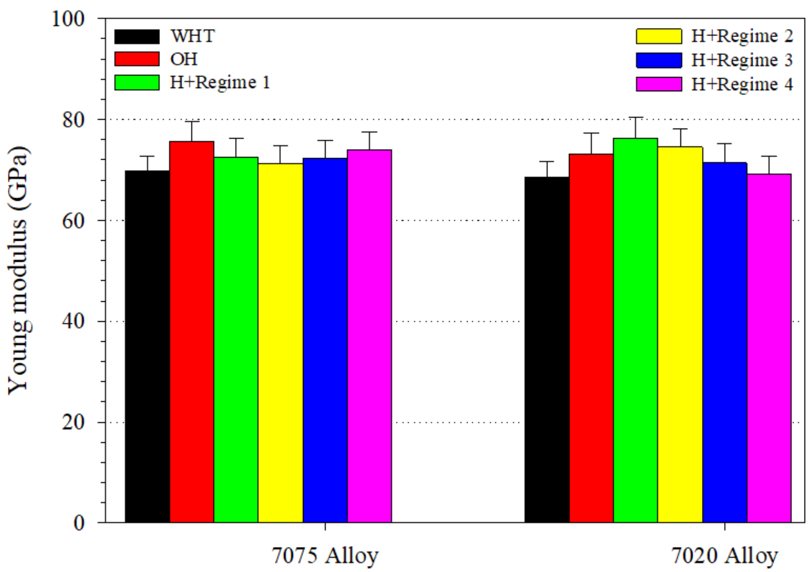


Table 2. Heat treatment (HT) conditions in which the mechanical properties reach peak value

Mechanical properties	Peak Values	Process
Microhardness (AA7075)	1920 MPa	Only Homogenization
Microhardness (AA7020)	1235 MPa	Regime 2
Ultimate tensile strength (AA7075)	425.1 MPa	Regime 4
Ultimate tensile strength (AA7020)	312.5 MPa	Only Homogenization
Tensile yield strength (AA7075)	378.2 MPa	Regime 4
Tensile yield strength (AA7020)	293.5 MPa	Regime 2
Elongation (AA7075)	6.6 %	Regime 4
Elongation (AA7020)	19.6 %	Regime 4
Compressive yield strength (AA7075)	501.6 MPa	Regime 3
Compressive yield strength (AA7020)	321.6 MPa	Regime 2
Young modulus (AA7075)	75.6 GPa	Only Homogenization
Young modulus (AA7020)	76.3 GPa	Regime 1

4. CONCLUSION

AA7075 and AA7020 alloys were produced using the vacuum furnace and the casting furnace. Mechanical properties of as-cast and heat-treated samples were investigated. The key findings are given as follows:

I. Substantial improvements in the microhardness of the AA7075 and AA7020 alloys were attained at different aging processes after solution treatment (300 ^{o}C/12h+475 ^{o}C/12h). Peak hardness values are obtained as 1920 MPa (OH) and 1235 MPa (regime 2), respectively.

II. The highest ultimate tensile strength as 425.1 MPa was obtained for the AA7075 alloy (regime 4). The peak elongation value in the AA7020 alloy (regime 4) reached to 19.6 %. T6 heat treatments (including different conditions and regimes) were improved significantly, both in the microhardness and tensile properties of both alloys. The increased microhardness and tensile strength in the aging treatments were attributed to a finer distribution of precipitates. This high precipitate density slows the dislocation movement and thus a higher stress is required for its bowing.

III. The compressive yield strength of the AA7075 alloy (regime 3) reached 501.6 MPa with the aging process (120 ^{o}C/12h+150 ^{o}C/12h) applied after the solution treatment (300 ^{o}C/12h+475 oC/12h). The maximum gain of this sample was calculated to be about 80.3%.

IV. There were no radical changes in Young's modulus for either alloy. Depending on the applied HT conditions, values in the range of 68-76 GPa were determined.

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