The Effect of Thermal Treatments on Structure and Mechanical Properties of High Strength Aluminum Alloys

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Abstract:- **The high strength aluminum zinc magnesium alloys are considered a target for many applications due to their remarkable high strength to weight ratio, resistance to corrosion and stress corrosion cracking. These alloys acquire their properties by the application of special heat treatment by aging for prolonged durations of time at specific temperatures preceded by a solid solution treatment. These prolonged times of conventional aging cycles are not recommended on the industrial scale.**

The objective of this research work is to investigate the effect of applying non conventional aging heat treatment cycles, in order to obtain, from one hand, the utmost mechanical characteristics of this alloy, and from the other, to shorten the total aging time to cope with the industrial requirements. Standard tensile specimens of one type of these alloys Al5Zn1.2Mg where treated at 475°C for 2 hrs, then quenched in water to obtain a supersaturated solid solution. Single aging was then carried out at 75°C, 125°C, 150°C, 175°C and 200°C for various aging times on the fist group of specimens. Another group of specimens from the Al5Zn1.2Mg aluminum alloy was subjected to double stage aging at 120°C for different aging times, then followed by a second aging cycle at 150°C for a fixed times of 2 hrs, 4 hrs, 6 hrs, 10 hrs and 15 hrs. The tensile characteristics, hardness, and structure properties of all specimens were determined.

The results showed that, the application of a single natural aging cycle for 1200 hrs, can provide a maximum hardness of about 117 HB , also a single aging cycle at 75°C, gives a peak hardness of 112 HB , after 96 hrs aging time. On the other hand, the implementation of double aging cycles by applying a first low temperature cycle at 120°C for 4 hrs, followed by a second high temperature aging cycle at 150°C for 10 hrs, provides an optimum hardness of a bout 120 HB, as a result from the formation of more finer precipitates. This indicates that, the application of double aging cycles showed a remarkable effect on shortening the time of the age hardening heat treatment and , in the same time , providing notably elevated mechanical properties.

INTRODUCTION

The wide range use of aluminum and aluminum alloys in the transportation industry (Aircraft, Automotive…..etc.), other machinery, and some semi finished products like (Pipes, Wires, Rods, Bars, Tubes, Building,…etc.) is based on superior mechanical characteristics of these alloys, low specific weight and corrosion resistance. Superior mechanical characteristics and optimal chemical properties of some aluminum alloys are obtained due to the possible application of structural hardening treatments.

Aluminum alloys are subdivided into two major groups, the first group responds to the precipitation hardening process where the strength increases as the coherency of the precipitates increases, on the other hand, the second one does not respond to the age hardening process, but strengthening takes place by increasing the dislocation density during cold working the alloy[1].

The Al-Zn-Mg series of alloys are one of the most considered heat treatable aluminum alloys providing a combination of remarkable physical, chemical and mechanical properties[2]. They can be strengthened by the precipitation of coherent precipitates based on the combination of zinc and magnesium with aluminum according to specific proportions during the age hardening treatments[3]. New high strength alloys with better mechanical properties than duralumin alloy were obtained based on AI-Zn-Mg-Cu system The strength of these alloys significantly exceeds that of duralumin (by 70-120 MPa) and widely used in industry. All the commercial alloys that comprise this group contain more zinc than magnesium. There are a few commercial alloys with Zn:Mg < 1 but they have been considered with the AI-Mg alloys· than of AI-Zn-Mg alloys. These alloys may be used for both casting and wrought products, but, because of the poor castability, the bulk is in the form of wrought products. Zinc and magnesium are the main alloying elements, High Zn:Mg ratio produces the best strength and response to heat treatment, together with the highest susceptibility to stress corrosion, low ratio produces the best weldability and the lowest quench sensitivity. A new classy of strong but weldable alloys based on the AI-Zn-Mg system is now being widely used in armor plates and military bridges. Production of medium strength Al-Zn-Mg alloys started in Sweden in 1959, and since then 22,000 tons have been extruded. From these volumes, about 4,000 tons have been used for military bridges and 10,000 tons for bumpers. The rest has been used for a great variety of applications, ranging from thin-walled tubes to heavy sections[4]. It is common on the European continent to use a Zn:Mg ratio of about 4:1 which provides a compromise between mechanical and corrosion properties. The Sum of magnesium and zinc usually lies between 5.5 to 7 [5]. Strength as function of Zn+Mg, drops markedly when the sum goes under 5.5%. Stress corrosion susceptibility increases with higher amount of Zn and Mg but no sharp change was noted at any particular composition [5]. In addition to zinc and magnesium, addition of manganese, chromium and zirconium are common [5]. In order to improve reliability and durability of structural alloys for modern aircraft structure, they should have improved resistance to fracture (fracture toughness) and corrosion resistance as well as high strength. . Strength properties and corrosion resistance of AI-Zn-Mg alloys may also be increased by the addition of small contents of manganese, chromium and zirconium. To increase plasticity and reliability characteristics in high strength alloys of the AI-Zn-Mg-Cu system, the contents of iron and silicon (unavoidable impurities in aluminum) should be limited [6]. Such a strong influence of iron and silicon impurity content on the plasticity of semi-finished products is related to the formation of coarse insoluble phases $A1_3Fe$, Al_3Fe and AlFeMnSi, precipitated in the form of stringers in the direction of precipitation. The homogenization regime for this alloy should satisfy several requirements. In the first place, homogenization should completely eliminate the prior dendritic segregation of the base alloying components, i.e., result in a solid solution of nonsoluble eutectic zinc-magnesium phases that precipitated upon solidification of the ingot and a uniform distribution of zinc and magnesium through out the cross section of the dendritic cells. Secondly, the time and temperature of homogenization should be adequate for decomposition of a supersaturated solid solution in aluminum with formation of particles of magnesium and zirconium intermetalloids. The precipitation process should not proceed so far as to make the particles grow to any considerable extent. Thirdly, from an economic standpoint, the time of homogenization should be minimal[7]. The purpose of solution heat treatment is to put the maximum particle amount of hardening solutes such as zinc, magnesium, copper or silicon into solid solution in the aluminum matrix. For some alloys, the temperature at which the maximum amount is soluble corresponds to the eutectic temperature, consequently, temperature must be limited to a safe level below the maximum to avoid consequences of over heating and partial melting. Heating rate to solution treatment influence grain size, and the high heating rates ensure that nucleation begins before the precipitates dissolve. Air is the usual heating medium, but molten salt baths or fluidized beds are advantageous in providing more rapid heating [8]. Quenching is in many ways the most critical step in the sequence of heat treating operations. The objective of quenching is to preserve the solid solution formed at the solution heat treating temperature, by rapidly cooling to some lower temperature, usually near room temperature. This statement applies not only to retaining solute atoms in solution, but also to maintaining a certain minimum number of vacant lattice sites to assist in promoting the low temperature diffusion required for Zone formation. During slow cooling from solution heat treatment temperature a coarse $MgZn_2$ precipitates are nucleated. On these results, it was accounted for quench sensitivity in terms of " loss of solute" mechanisms that is by admitting that the formation of large precipitates depleting the matrix of solute available for aging; causing a marked decrease of hardening capability [9]. The aging of rapidly quenched AI-Zn-Mg alloy from room temperature to relatively low aging temperature is accompanied by the generation of GP zones having an approximately spherical shape. With increasing aging time, GP zones increase in size and the strength of the alloy increases [10]. Extended aging at temperatures above room temperature transforms the GP zones in alloys with relatively high zinc-magnesium ratio into the transition precipitate known as η´ or M´ , the precursor of the equilibrium $MgZn_2$, η or M phase precipitate. The basal planes of the hexagonal precipitates are partially coherent with the {111} matrix p1aned but the interface between the matrix and C direction of the precipitate is incoherent [10]. Aging time and temperature that develop the highest strength, characteristics of the T_6 temper produce zones having an average diameter of 2 to 3.5 nm (20-35 A°) along with some amount of η´ The nature of these zones is still uncertain, although they undoubtedly have high concentrations of zinc atoms and probably magnesium atoms as well.

EXPERIMENTAL WORK

A high strength Aluminum - Zinc - Magnesium alloy were used for this research work. The aluminum alloy Al5Zn1.2Mg was received in the form of rolled sheets of 8mm thickness. The alloy was in the T6 temper state. The chemical compositions of this alloy is shown in table (1),it was determined by Elvatech hand held x-ray fluorescent spectrophotometer .

Table (1) Chemical composition of the used aluminum alloys

	Zn%	Mg %	Cu %	Fe%	Si%	Mn %	Ti%	Zr%
Al5Zn1.2Mg	5	1.2	0.2	0.3	0.15	0.25	0.1	0.15

The specimens were machined according to ASTM specifications [11]. For solution heat treatment, and age hardening, an electric resistance furnace Naber type (D-2804) with maximum heating temperature of 1600°C was used. During this simple cycle the specimens were heated up to 475°C at a heating rate of 200/hr and they were held at this temperature for 2 hours. Specimens were then quenched in water to obtain a supersaturated solid solution. The program of the experimental work of the thermo regimes is demonstrated in table (2). The determination of tensile properties were done on a 100 KN Instron electrohydraulic universal testing machine, model 8032.

Table (2) The program of the experimental work of the thermo regimes

Group No.	Test Conditions
NATURAL AGING	
1	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged naturally at 20°C for 120, 240, 480, 720, 960, 1200, 1440 and 1680 hrs.

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	SINGLE AGING
2	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged at 75°C for 20, 30, 40, 50, 60, 70, 80, 96 and 110 hrs.
3	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged at 125°C for 5, 10, 15, 20, 25 and 27 hrs.
4	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged at 150°C for 1, 2, 3, 4, 5 and 6 hrs.
5	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged at 175°C for 25, 30, 35, 40, 45, 50 and 55 min.
6	• Solution treated at 475°C for 2 hrs then quenched in water. • Aged at 200°C for 5, 10, 15, 20, 25 and 30 min.
	DOUBLE AGING
7	• Solution treated at 475°C for 2 hrs then quenched in water. • 1st cycle aged at 120°C for 7, 8, 9, 10, 11, 12 and 13 hrs. • 2nd cycle aged at 150°C for a fixed time of 2 hrs.
8	• Solution treated at 475°C for 2 hrs then quenched in water. • 1st cycle aged at 120°C for 2, 3, 4, 5, 6, 7, 8, 9 and 10 hrs. • 2nd cycle aged at 150°C for a fixed time of 4 hrs.
9	• Solution treated at 475°C for 2 hrs then quenched in water. • 1st cycle aged at 120°C for 2, 3, 4, 5, 6, 7 and 8 hrs. • 2nd cycle aged at 150°C for a fixed time of 6 hrs.
10	• Solution treated at 475°C for 2 hrs then quenched in water. • 1st cycle aged at 120°C for 1, 2, 3, 4 and 5 hrs. • 2nd cycle aged at 150°C for a fixed time of 10 hrs.
11	• Solution treated at 475°C for 2 hrs then quenched in water. • 1st cycle aged at 120°C for 1, 2, 3, 4 and 5 hrs. • 2nd cycle aged at 150°C for a fixed time of 15 hrs.

Vickers hardness test has been used to obtain reliable average hardness reading. Hardness a test was carried out at different locations along the gauge length of the the applied load was one Kg. The specimens for metallographic observation were prepared to allow studying the structure of the aluminum alloys which were treated thermally. Specimens of aluminum alloy Al5Mg1.2Zn were first prepared by grinding using different grades of emery papers (180, 220, 320, 400 and 600), then mechanically polished with a fine abrasive powder of Al_2O_3 suspended in water solution. Etching was carried out by using a killer`s etchant (1% Hf + 1.5% HCl + 2.55 HNO3 + 95% H2O) by immersing for 20-30 sec., and then washing in a stream of warm water. Structure was investigated using the scanning electron microscope type REMMA 202.

RESULTS AND DISCUSSION:

Fig.(1) illustrates the stress-strain curve of the aluminum alloy Al5Zn1.2Mg obtained immediately after solution treatment at 475°C for 2 hrs followed by quenching in water. The obtained ultimate tensile strength was 250 MPa which is considered a relatively low value since in this state all the solute atoms are in the solution and no second phase particles are manifested in the structure. Fig.(2) demonstrates the effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single natural aging cycle at 20°C after solid solution treatment at 475°C for 2 hrs . At zero aging time which corresponds to the solid solution treated state, the hardness as indicated before was 51 HV. The hardness increases gradually with time to attain a maximum value of 117 HV after 70 days . It can be noted that a high rate of hardness increase is obtained in the initial stages of aging at room temperatures up to 30 days where the rate is substantially decreased to attain 115 HV after 50 days . It was found that the initial rate up to 30 days was about 2.6 HV/day while from 30 days up to 50 days, it was only about 0.5 HV/day. This can indicate that the grain of hardness after 30 days at room temperature is relatively limited.

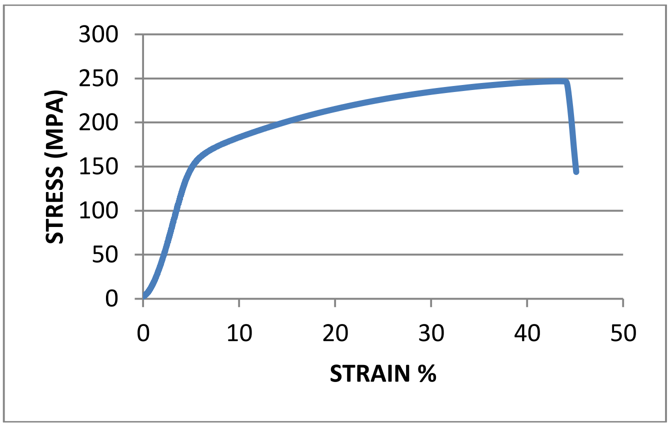

Fig (1) The stress-strain curve of the material after solid solution at 475°C for 2 hrs

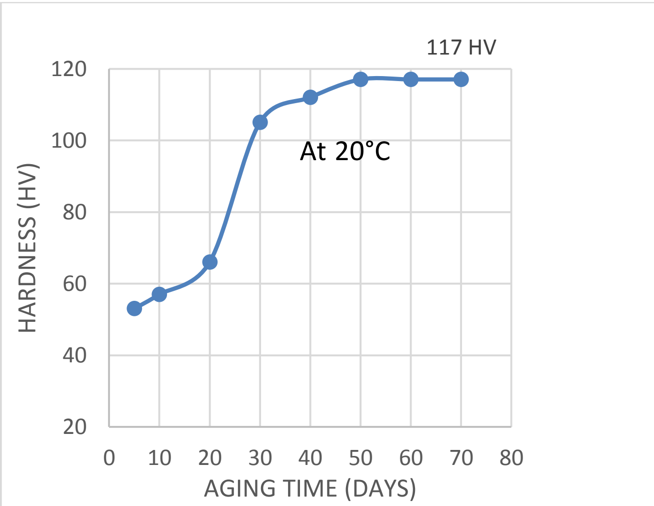

Fig. (2) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single natural aging cycle at **20°C** after solid solution treatment at 475°C for 2hrs

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solute rich GPI zones with relatively lower contents of Mg are formed [50-53]. These zones take the form of thin disks coherent with Al matrix on the {100} $_{Al}$ planes, and having an internal order of zinc atoms. As aging continuous, more Zn and Mg atoms diffuse to the GP-I precipitates which become more thick disks and transform to what is called " GP-II" zones with relatively high Zn/Mg ratio on the { 111 }$_{Al}$ planes. With continuous diffusion a long the aging time at the prescribed aging temperature, these precipitates develop to greater degree of order and take the form of hexagonal structure known as " η' " non-equilibrium precipitates [54] .The basal planes of their hexagonal structure are partially coherent with the { 111 }$_{Al}$ matrix planes . The interface between the matrix and the C direction of the precipitates is incoherent [52]. In this stage of partial coherency of these precipitates maximum strengthening could be obtained and the alloy is considered to be in the aged condition. Further prolonged aging leads to the formation of the stable " η " equilibrium precipitates which are incoherent, in all direction, with the Al matrix. The lose of coherency in this final stable equilibrium precipitates drive to the decrease of mechanical precipitates and the alloys considered to be in the overage condition and the strength begins decrease . When the aging temperature was increased to 125°C, as shown in Fig. (4) which illustrates the effect of aging time on the measured hardness of the prescribed alloy during a single aging cycle at this temperature, a peak of hardness of about 109 HV was obtained after aging time of 25 hrs.

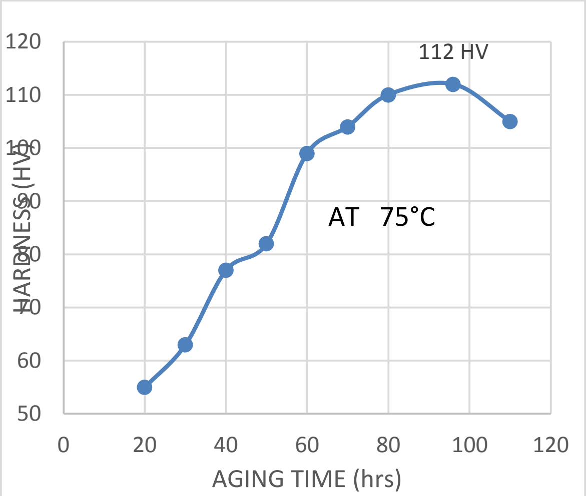

Fig. (3) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single aging cycle at **75°C** after solid solution treatment at 475°C for 2hrs

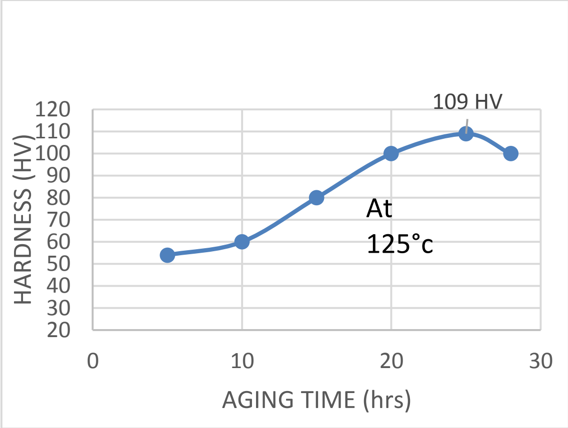

Fig. (4) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single aging cycle at **125°C** after solid solution treatment at 475°C for 2hrs

The effect of the aging time on the hardness of the same alloy during, also, a single aging cycle at 150°C is illustrated in Fig. (5). This figure emphasizes that a lower peak hardness can be obtained at a shorter aging time by increasing the aging temperature . The results indicates that a maximum hardness value of 93 HV can be obtained after only 5 hrs aging time at 150°C. Fig.(6), Fig.(7) demonstrate the effect of aging time on the obtained hardness of aluminum alloy Al5Zn1.2Mg during a single aging cycle at 175°C, 200°C respectively . In this range of relatively high aging temperature, the value of the coefficient of diffusion of the solute atoms in the aluminum matrix will be more enhanced which leads to higher kinetics of the precipitation process. This leads to rapid coarsening and incoherency of the formed precipitates. Consequently, this results in rapid gain of the peak hardness and quick attainment of the undesirable overageing range. A peak hardness of 82 Hv and 78 Hv, where obtained at aging temperatures of (175°C - 200°C) after aging time of 45 min & 20 min respectively .

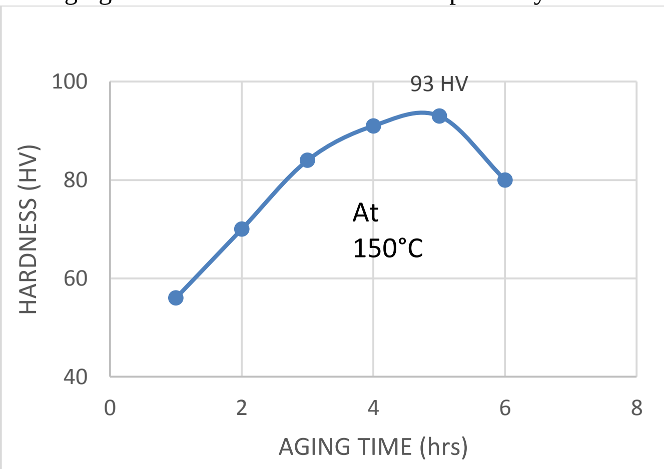

Fig. (5) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single aging cycle at **150°C** after solid solution treatment at 475°C for 2hrs

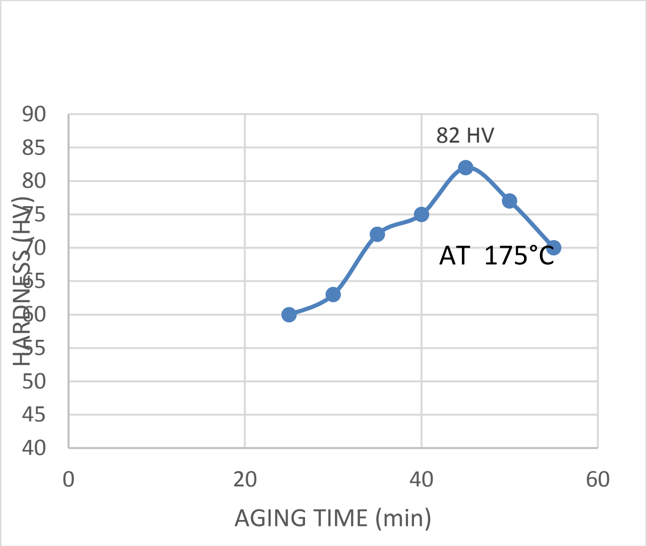

Fig.(6) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single aging cycle at **175°C** after solid solution treatment at 475°C for 2hrs

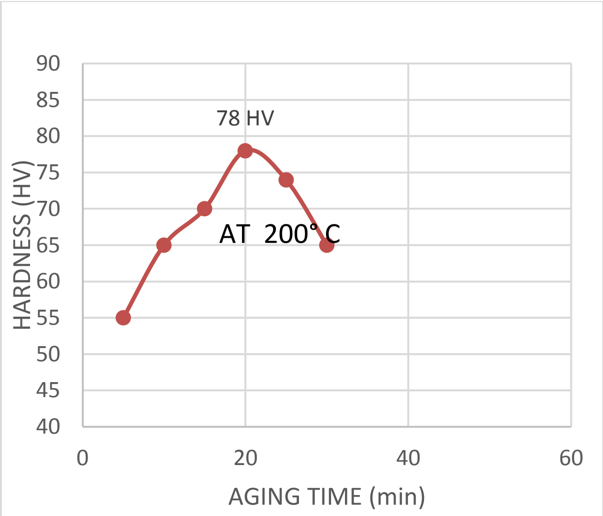

Fig.(7) Effect of aging time on the hardness of the aluminum alloy Al5Zn1.2Mg during a single aging cycle at **200°C** after solid solution treatment at 475°C for 2hrs

The comparison between the hardness distribution obtained, on the prescribed alloy, during a single aging cycle, in the medium temp aging range, at 125°C and 150°C is elucidated in Fig.(8) The measured values indicates that increasing the aging temp in the aging range by only 25°C, from 125°C to 150°C, remarkably increases the coefficient of diffusion of solute elements and increases the rate of the precipitation process and particularly the growth of precipitates [12] . Aging time was reduced to about one fifth of its value while the hardness is sensibly reduced by about 15 % . These results point out that, this range of aging temperature is convenient since it provides reasonable mechanical properties at acceptable period of aging time , with no excessive coarsening of precipitates [13] .

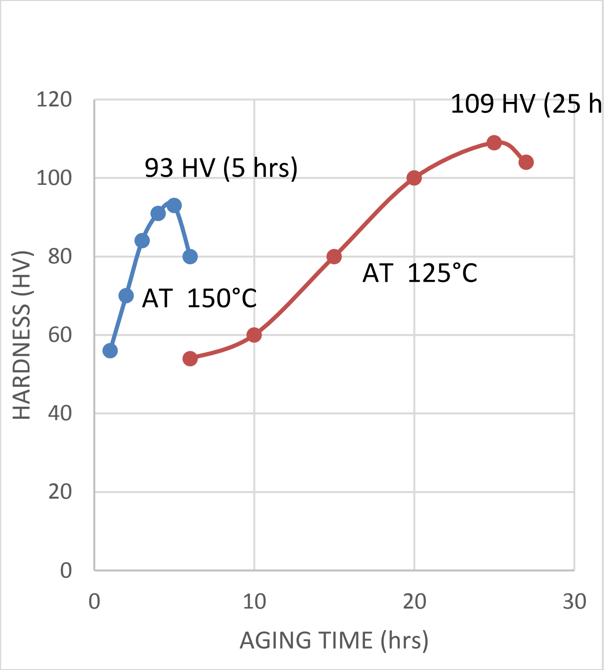

Fig. (8) comparison between the hardness distributions of the aluminum alloy Al5Zn1.2Mg obtained during a single aging cycle, in the medium temperature aging range, at **125°C** and at **150°C** after solid solution treatment at 475°C for 2hrs

Fig.(9) visualizes the effect of temperature of a single aging cycle on the time to peak hardness obtained on the aluminum alloy Al5Zn1.2Mg after solid solution treatment at 475°Cfor 2 hrs . It can be noted that, the time to peak hardness drops in a very pronounced manner up to an aging temperature of 150°C. At higher temperatures, the rate of drops is less intense. This also can affirm that, an aging temperature of around 150°C is considered as an optimum aging temperature securing a convenient aging time.

Fig.(10) illustrates the microstructure obtained on this alloy after applying a single aging cycle at 150°C for 5 hrs. We can clearly observe, the dispersed second phase particals (non equilibrium η' precipitates) in a homogenous solid solution matrix of Al with both Zn and Mg.

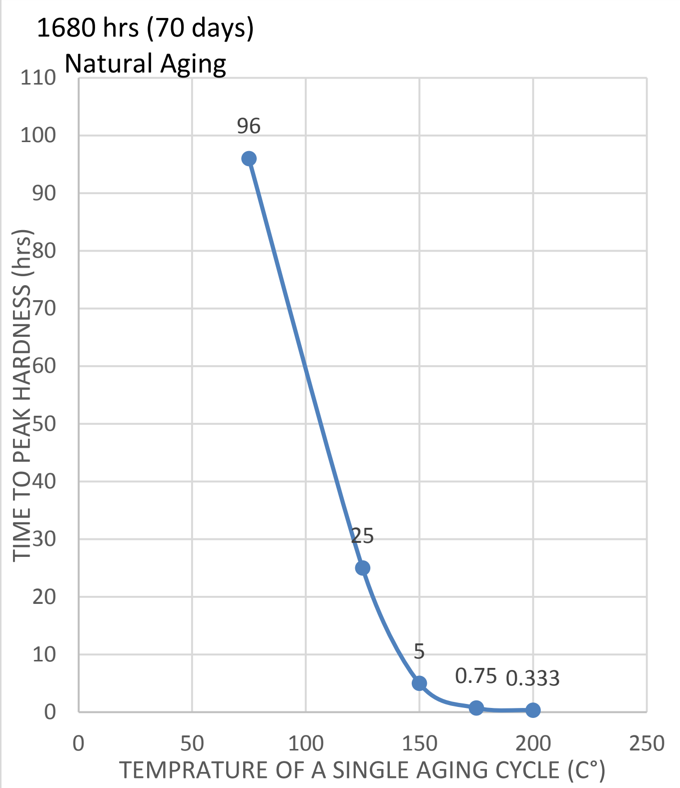

Fig.(9) Effect of temperature of a single aging cycle on the time to peak hardness obtained on the aluminum alloy Al5Zn1.2Mg after solid solution treatment at 475°C for 2 hrs

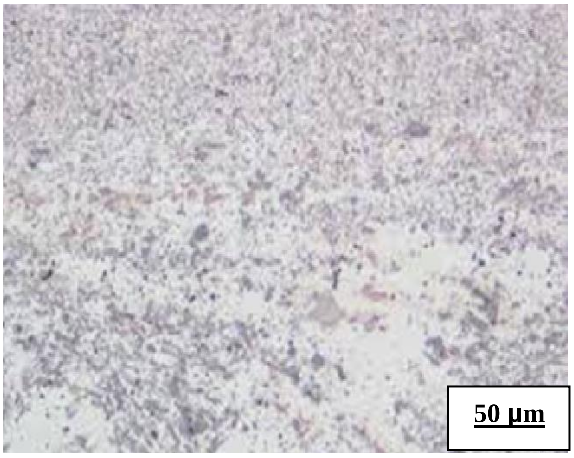

Fig.(10) Microstructure of the aluminum alloy Al5Zn1.2Mg after solid solution treatment at 475°C for 2 hrs followed by a single aging cycle at 150°C for 5 hrs

The effect of temperature of a single aging cycle on the elongation percentage of the peak of ultimate tensile strength obtained on the aluminum alloy Al5Zn1.2Mg after solid solution treatment at 475°C for 2 hrs is shown in fig (11). A clear maximum ductility (elongation percentage) was manifested at an aging temperature of 125°C where the ductility starts to decrease at higher aging temperatures. When the aging temperature is increased from 125°C to 150°C, slight decrease of ductility in the order of 6% can be recorded. This indicates that in this range of aging temperatures (125°C - 150°C), this alloy, can provide, in addition to convenient aging time and reasonable ultimate strength , a maximum ductility.

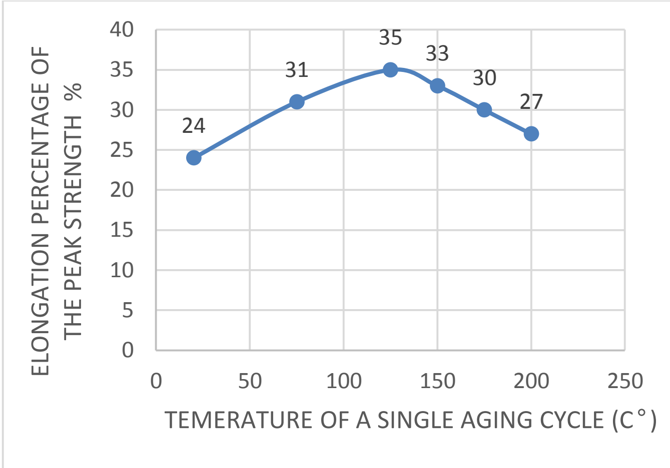

Fig.(11) Effect of temperature of a single aging cycle on the elongation percentage of the peak of ultimate strength obtained on the aluminum alloy Al5Zn1.2Mg after solid solution treatment at 475°C for 2 hrs

Fig (12) , fig (13) illustrate the stress – strain curves of aluminum alloy Al5Zn1.2Mg after a single aging cycle at 125°C for 25 hrs, and at 150°C for 5 hrs , respectively . These obtained curves demonstrate a serrated or jerky flow during plastic deformation . This behavior is known as " Portevin – Le Chatelier " effect (PLC) and has long been associated with dynamic strain aging or the competition between diffusing solute atoms pinning the dislocations and the moving dislocations scabbing and breaking free of this stoppage [14-20] .

This process starts at a so-called critical strain, which is a minimum strain needed for the onset of the serration in the stress – strain curve. This critical strain is both temperature and stain rate dependent [21].

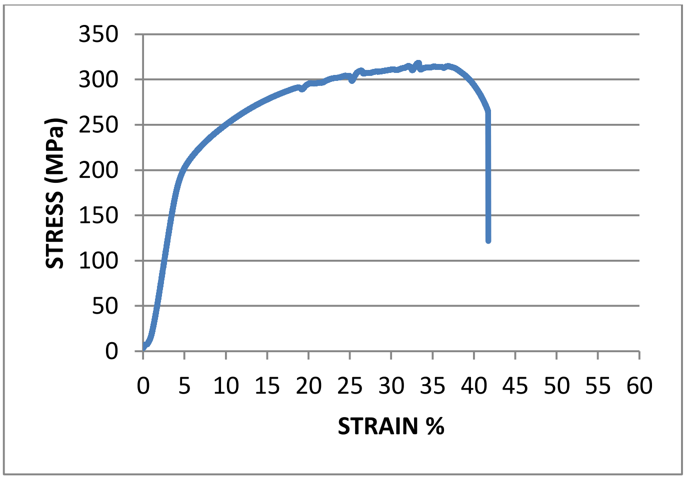

Fig. (12) The Stress-Strain curve of the aluminum alloy Al5Zn1.2Mg after a single aging cycle at 125°C, for 25 hrs

International Journal of Engineering Research & Technology (IJERT)
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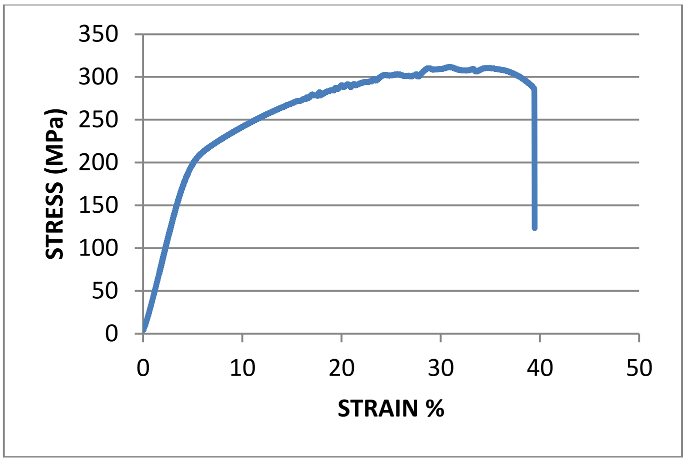

Fig. (13) The Stress-Strain curve of the aluminum alloy Al5Zn1.2Mg after a single aging cycle at 150°C, for 5 hrs

Almost all the obtained serration on the strain stress cures of the aluminum alloy Al5Zn1.2Mg after a single aging cycle at 125°C and 150°C for 25 hrs and 5 hrs, respectively , are of the C-type. On the other hand, the majority of serrations, manifested on the stress–strain curves of aluminum alloy Al5Zn1.2Mg after a single aging cycle at 175°C, and 200°C , for 45 min and 20 min, respectively, are of the A-type as illustrated in Fig (14) , Fig (15) .

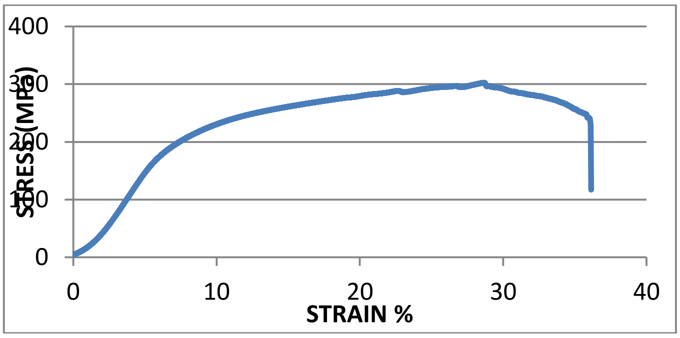

Fig.(14) The Stress-Strain curve of the aluminum alloy Al5Zn1.2Mg after a single aging cycle at 175°C, for 45 min

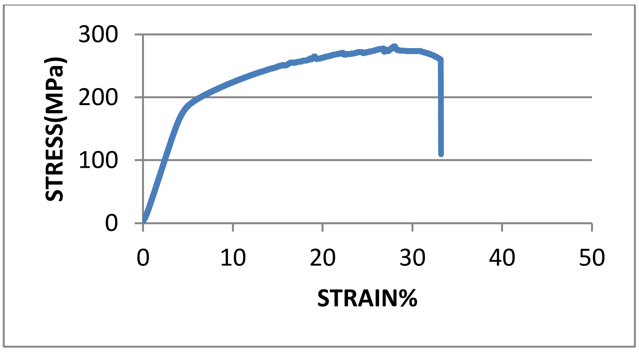

Fig.(15) The Stress-Strain curve of the aluminum alloy Al5Zn1.2Mg after a single aging cycle at 200° C, for 20 min

Double stage aging at different temperatures can provide the advantages of both low and high aging temperatures starting the aging process at relatively low temperatures, allows the formation of large number of nucleation sites of the coherent precipitates. When the aging process is continued in a second stage at relatively higher aging temperatures, the rate of growth is enhanced and reduces significantly the aging time . Fig (16) , Fig (17) , Fig (18) , Fig (19) and fig (20) illustrate the effect of aging time, of a first low temperature aging cycle at 120°C, on the hardness of the aluminum alloy Al5Zn1.2Mg, after a second aging cycle at 150°C, for a fixed times of 2, 4, 6, 10 and 15 hrs, respectively .

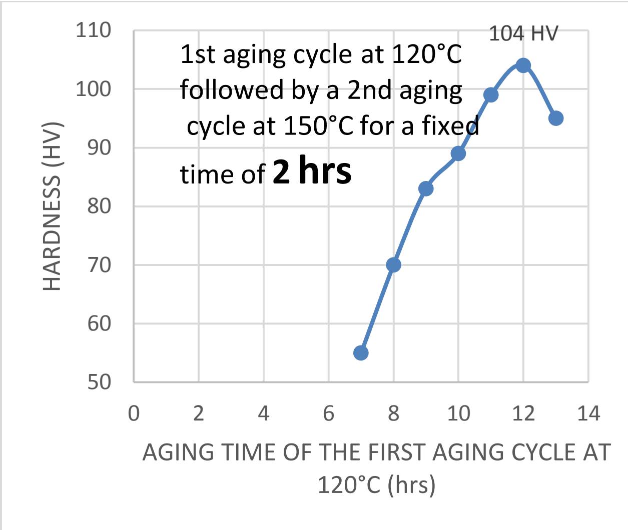

Fig.(16) Effect of aging time of the first aging cycle at 120°C on the hardness of the aluminum alloy Al5Zn1.2Mg followed by a second aging cycle at 150°C for a fixed time of **2 hrs**

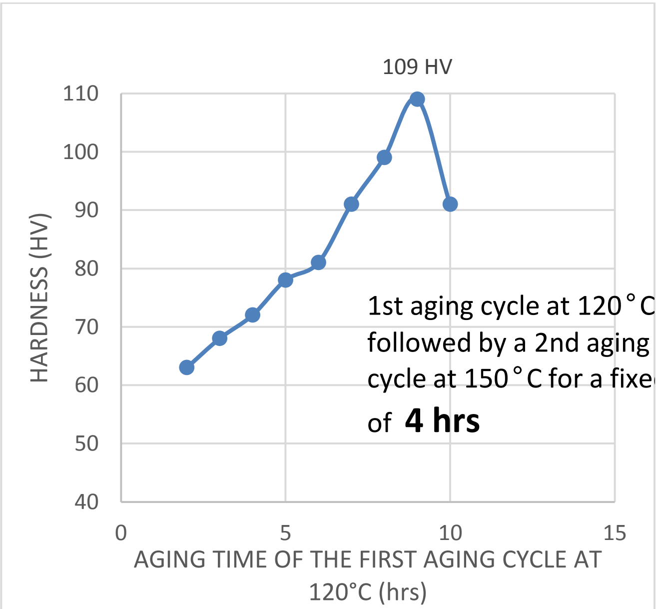

Fig.(17) Effect of aging time of the first aging cycle at 120°C on the hardness of the aluminum alloy Al5Zn1.2Mg followed by a second aging cycle at 150°C for a fixed time of **4 hrs**

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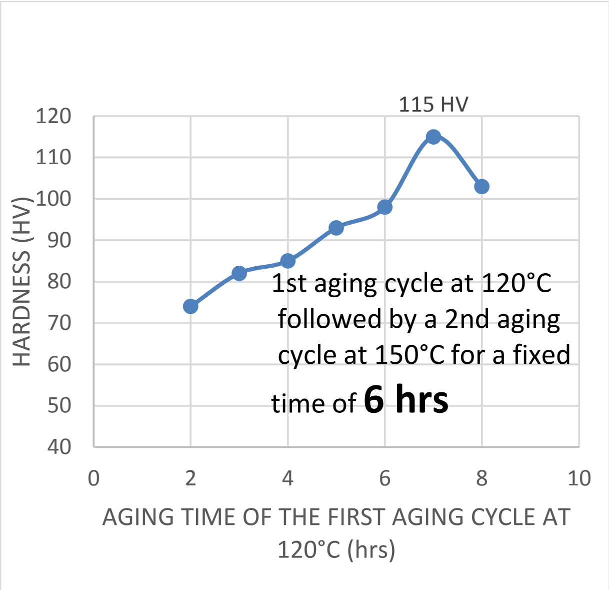

Fig.(18) Effect of aging time of the first aging cycle at 120°C on the hardness of the aluminum alloy Al5Zn1.2Mg followed by a second aging cycle at 150°C for a fixed time of **6 hrs**

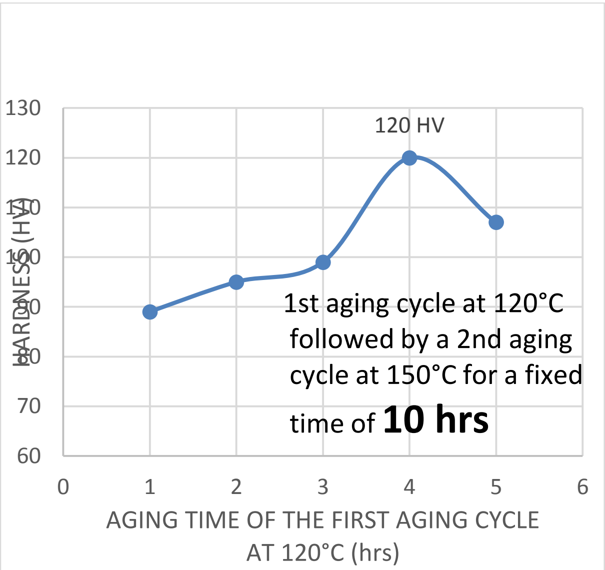

Fig.(19) Effect of aging time of the first aging cycle at 120°C on the hardness of the aluminum alloy Al5Zn1.2Mg followed by a second aging cycle at 150°C for a fixed time of **10 hrs**

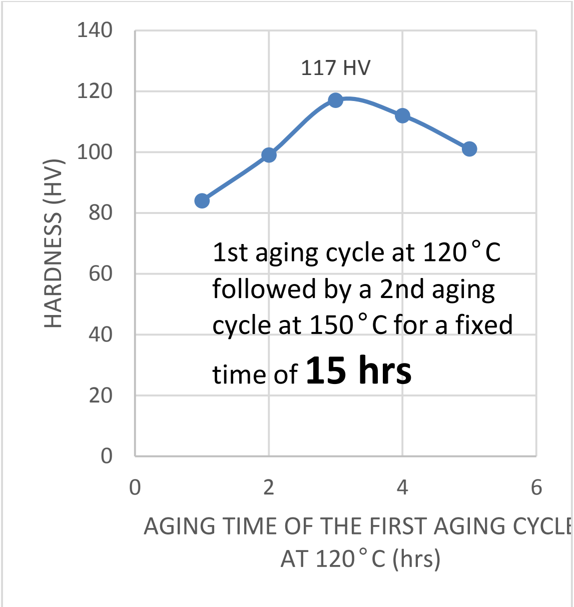

Fig.(20) Effect of aging time of the first aging cycle at 120°C on the hardness of the aluminum alloy Al5Zn1.2Mg followed by a second aging cycle at 150°C for a fixed time of **15 hrs**

In Fig (16) we can remark that , a peak value of hardness of the order of 104 HV was obtained after two stage aging first at 120°C for 12 hrs followed by a second aging cycle at 150°C for 2 hrs. When the time of the first aging cycle exceeds 12 hrs, overaging takes place and precipitates , which are grown up during the second aging cycle, will lose their coherency with the matrix. When the second aging cycle at 150°C was prolonged to 4 hrs, the peak hardness was increased to about 109 HV while the aging time, of the first aging cycle, to attain this peak, was shorten to only 9 hrs, as shown in Fig (17) . This confirms that, an increase of peak hardness in the order of 5 % can be obtained when the second aging cycle was increased from 2 hrs to 4 hrs after the application of a low temperate aging cycle at 120°C .

Further increase of the aging time, of the second aging cycle at 150°C up to 10 hrs, after a first aging cycle at 120°C , leads to increasing the obtained peak hardness by about 15 % relative to the corresponding value when the aging time of the second cycle was in the order of only 2 hrs, as shown in Fig (18) , Fig (19) .

Moreover, by increasing aging time, of the second aging cycle, to 15 hrs, results in reducing the peak hardness obtained after applying the double stage aging cycle as shown in Fig (20) . These results indicate that, an optimum hardness of about 120 HV can be obtained, on the prescribed alloy, by applying a first low temperature aging cycle at 120°C , for 4 hrs followed by a second high temperature aging cycle at 150°C for 10 hrs. The obtained microstructure after applying this type of double aging cycle indicates a sensible reduction of the size of the transition precipitates η' relative to the same precipitates obtained after the application of a single aging cycles, as shown in Fig(21).

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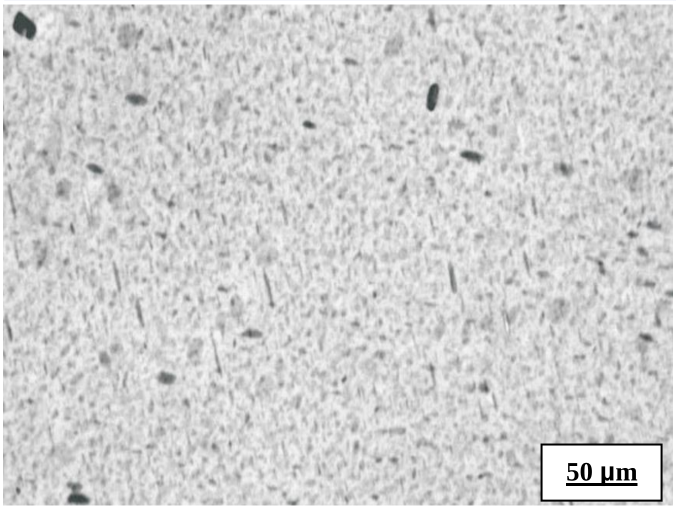

Fig.(21) Microstructure of the aluminum alloy Al5Zn1.2Mg after a solid solution treatment at 475ºC for 2 hrs followed by a double aging cycle, one cycle at 120ºC for 4 hrs followed by a high temperature cycle at 150ºC for 10 hrs

Fig (22) demonstrates the time to peak of the second aging cycle at 150°C after a first aging cycle at 120°C. This figure visualize the optimum aging time in both low and high aging cycle to secure the highest values of hardness on this alloy. Both aging temperatures and aging times control the kinetics of nucleation and growth of the coherent precipitates and their evolution towards the non-coherent state. In fact, the low aging temperature secures a nucleation regime allowing the formation of fine dispersed second phase particle , due to , the low values of the coefficient of diffusion in this range of temperatures. This can also guarantee relatively uniform distribution of precipitates nucleation sites that can provide dispersion strengthening. When a second high temperature cycle is applied after the low temperature one, most of the solute atoms, where found out of solution and jointed the formed clusters and precipitates. This implies that very limited nucleation processes may take place in this high temperature range since the solution is depleted from the solute atoms. On the contrary, enhanced growth processes of the already formed precipitates occur. These consecutive low and high temperature aging regimes prohibited the coagulation of precipitates and achieve finally dispersed precipitates.

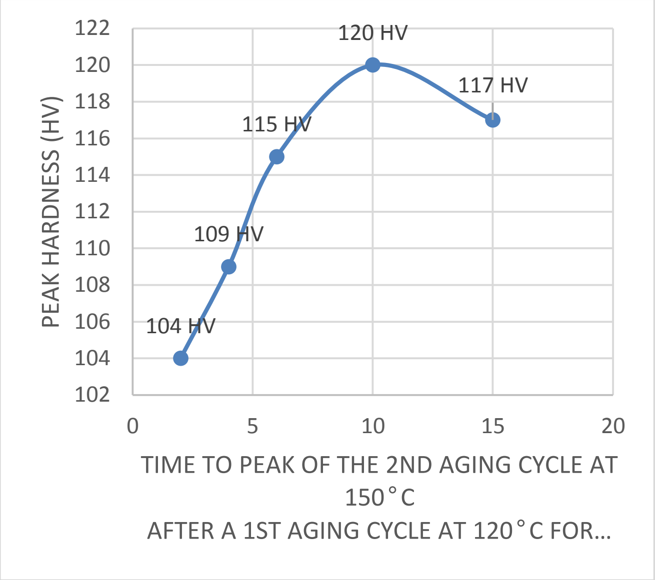

Fig.(22) Effect of time to peak of the 2nd aging cycle at 150°C preceded by a 1st aging cycle at 120°C on the peak hardness of the aluminum alloy Al5Zn1.2Mg

CONCLUSIONS

(1) The application of a single natural aging cycle for 50 days (1200 hrs) on the aluminum alloy Al5Zn1.2Mg after a solid solution treatment at 475°C for 2 hrs followed by quenching in water, can provide a maximum hardness of about 117 HV. Prolonged aging time at room temperature above 1200 hrs (50 days) , does not result in a substantial increase in the measured values of hardness.

(2) As the aging temperature increases from 75°C to 200°C, the aging time to reach peak hardness decreases from 96 hrs to 0.33 hrs , which is a considerable reduction in the time of the process of heat treating this alloy, and which is remarkably very important and required on the industrial scale. Furthermore, the corresponding peak hardness values, also decrease from 112 HV to 78 HV , which is about 30%.

(3) An aging temperature of 150°C can be recommended for this alloy, this temperature can provide a reasonable hardness of 93 HV , that is lower by only 17% relative to that obtained when the aging temperature was 75°C, while the corresponding aging time was sensibly reduced to only 5 hrs, relative to the corresponding time of the peak value at the same temperature (96 hrs).

(4) Portevin-Le chatelier effect (serreted flow) appears also on the stress-strain curves of this alloy after the application of single aging cycles, with substantial amplitudes. This effect is associated with dynamic strain aging by the competition between moving dislocations, from one hand and solute atoms and precipitates, from the other.

(5) The application of double stage aging (one aging cycle at relatively low temperature followed by a second cycle at higher temperature) can secure better mechanical properties at relatively shorter aging times, due to the formation of more finer precipitates.

(6) An optimum hardness of about 120 HV can be obtained, on the prescribed alloy, by applying a first low temperature aging cycle at 120°C , for 4 hrs, followed by a second high temperature aging cycle at 150°C for 10 hrs.

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