Effect Of Quenching Temperature On Structure And Mechanical Properties Of Aluminum Alloy With High Magnesium Content Al-10% Mg

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Abstract: Development of new high element aluminium alloys requires of solving features related to the modes of their thermal hardening. In the present work the quenching temperature interval choice of alloy with a high content of magnesium Al-10% Mg is determined. For this purpose, water quenching of extruded bars from alloy was carried from the temperatures leying in the region of the maximum solubility of magnesium in aluminum. The change of Brinell, Rockwell hardness, tensile strength, yield strength, elongation, toughness of alloy samples, cut at an angle of 0 and 90 ° to the axis of compression were found. The analysis of the microstructure using optical metallographic microscope at a magnification of 500 was worked out. It is shown that the tensile strength, elongation, toughness, hardness decreases, yield stress of the samples cut in the longitudinal and transverse direction rise with increasing quenching temperature. The temperature of quenching is set, providing a combination of high strength and toughness properties. The results obtained are discussed from the perspective of the completeness of dissolution of dispersed intermetallic phases. Results can be used during editing operations and wrought and semi-finished products stamping of aluminum alloy with a high content of magnesium.
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1. Introduction

Alloys of Al-Mg system are materials with one of the highest rates of specific strength. Magnesium additives help reduce the specific gravity, to increase strength while maintaining good corrosion resistance and weld ability (Mondolfo L. F., 1976).

Typically, the maximum content of magnesium in the wrought aluminum alloys is limited to 5-6%, for example alloys 5056, 5356 (Heat Treater's Guide, 1996). Rising of magnesium content above these values may causes in casting difficulties, hot and cold deformation and heat treatment (Fakhraei O. et al, 2013, Fakhraei O. et al, 2014). Modification using, applying of pulsed electromagnetic fields, other secondary treatment methods can solve a number of issues and improve casting formability of aluminum alloys containing about 10% magnesium (Fernández R. et al, 2012, Fourmeau M. et al, 2013, Zhivoderov V.M. et al, 1997). For example, the acoustic exposure causes an increase in the crystallization process of melt viscosity and heat and mass transfer coefficient variation due to changes in the physical properties of the melt. Furthermore, this effect decreases in the oxide and non-metallic inclusions content in the alloy. This is due to the ejection of non-metallic and oxide inclusions to the surface of the melt during product solidification. This increases the rate of heat transfer, launch new crystallization centers and the effect of structure refinement is observed (Aluminum Alloy Castings, 2004, MA Cheng-guo et al, 2014).

The maximum content of magnesium in refractor aluminum alloys is limited to 20% at nowdays, but this experimental alloys for shaped castings (Fakhraei O. et al, 2013), they are not serial and industrial. However, cast structure has several drawbacks: the heterogeneity of the dendrite structure, the presence of shrinkage and gas pores, element segregation. Ingot homogenization is applied as a first heat treatment in the technological process. Ingot with inhomogeneous thermodynamic unstable structure undergoes to annealing, which resulted in more homogeneous structure, ductility increases, which allows subsequent processing to greatly intensify pressure (compression) and reduce process waste. In many cases homogenization can improve the properties of deformable semi finished (Bensaada S. et al, 2011).

A significant portion of the casting defect can be eliminated by hot and cold working (Jie J.C. et al, 2013, Man-ping Liu et al, 2012). In the process of homogenized ingot hot rolling there heat cracks are formed caused by the presence of brittle β-phase, both separately and in a non-equilibrium eutectic (Sauvage X. et al, 2014).

Application of hydrostatic compression scheme lets receive in extruded panels' thickness of about 6 mm when pressing ingots in return for their hot rolling (Cepeda-Jiménez C.M. et al, 2009, Demirci H.i. et al, 2012). Further cold rolling requires addressing of ductility improve by softening heat treatment, including interoperation annealing. However, the mechanical properties set are provided by quenching and aging on the final stage of heat treatment (Golovin I.S. et al, 2013). The effectiveness of the hardening heat treatment of aluminum alloys depends on the aging mode and a homogeneous structure of a supersaturated solid solution after the quenching (Maisonnette D. et al, 2010). A presence of heterogeneous inclusions is possible at a reduced temperature of heating for quenching and slow cooling, which may prevent further decay in aging and reduce the set of properties (Zou B. et al, 2014, Grechnikov F.V. et al, 2009). Inflated heating temperature give rise to excessive thermal stresses lead to warping, raise the cost of production.

The goal of this work was to study the effect of quenching temperature on the structure, mechanical properties, the nature of hardening of aluminium alloy Al-10% Mg and the set of processing modes, providing a combination of high strength and plastic properties.

2. Materials and Metods

The chemical composition of the alloy was determined by energy-dispersive consoles of SEM Tescan Vega, presented in Table 1.

Table 1. Mass fraction of elements in the alloy Al-10%Mg.

. Mass fraction of elements, %							
Mg	Zr	Be	Ti	B	Cu	Co	Al
10,5	0,11	0,08	0,018	0,01	0,001	0,015	89,266

Manufacturing process of extruded semi-finished included:

- round ingots casting with diameter of 127 mm and a length of 700 mm in the semi-continuous casting installation in the mold DC solenoid (Zuo Y. et al, 2005);
- homogenizing the ingot at a temperature of 750K within 15-17 hours;
- hot-pressing the strip (6 × 15 × 115 mm) at a temperature of 700-720K with the air cooling.

From pressed strips the samples of rectangular cross-section of 6x10 mm in length 115 mm were cut in the direction 0 and 90^0 to the extrusion axis. The samples were heated to a temperature of 650 K, 690 K, 710 K, 740 K in the laboratory furnace, then cooling was in usual water. Quenching temperature is chosen so as to ensure of various dissolution completeness of disperse phase beta β (Al_8Mg_5). After quenching, the samples were tested for hardness Brinell HB (indenter diameter 2.5 mm), Rockwell HRB (indenter diameter 1,588 mm). Uniaxial tensile test was performed on the test vehicle Testometric. They are allowed to determine the tensile strength σ_b (МПа), yield strength $\sigma_{0,2}$ (МПа), elongation δ (%). Toughness KCU was evaluated by mechanical impact tester.

Since extruded semi-finished can undergo the cold deformation when straightening, bending, hooking and other shaping operations, as well as work hardening to improve the strength characteristics the effect of material hardening at different modes of quenching was studied in the work.

To this aim, the curves of dependence the engineering strength and engineering deformation were obtained from tensile diagrams. For this purpose portion of the residual strain were divided into 5-6 parts (Figure 1). That gave the value of intermediate lengths $l_i=l_0+\Delta l_i$, mm. here l_0 – initial sample length.

For each intermediate length P_i was determined on the load axis, and then the current cross-sectional area was calculated $F_i = F_0 \times l_0 / l_i$, F_0 – initial sectional area of the sample, mm^2. Then the engineering strength was found by the formula: $\sigma_i = P_i / F_i$. Current deformation ε_i was calculated by formula: $\varepsilon_i = \ln(l_i / l_0) \times 100\%$.

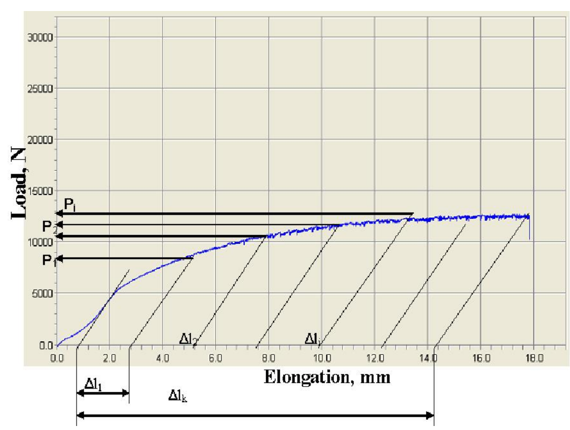

Figure 1 - Diagram to find the current lengths and load

Microsections were produced for metallographic analysis of the thermally treated samples. The following composition was subjected to etching 95% H_2O, 2% HF, 3% HNO_3.

3. Results

Results of hardness depending upon the quenching temperature are shown in Figure 2.

From Figure 2 it cam be seen that hardnes drops due to rosing of quencing temperature. However hardnes HRb starts to rise slowly from temperature 655K.

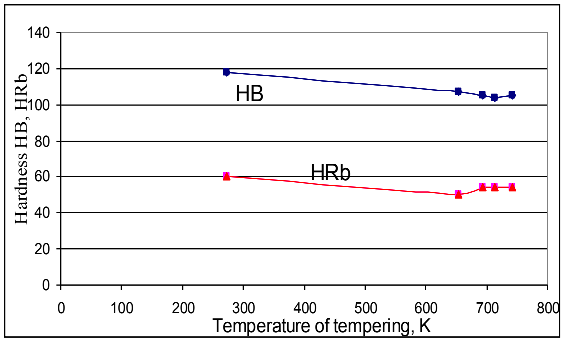

Figure 2 - The hardness of samples depending upon the quenching temperature

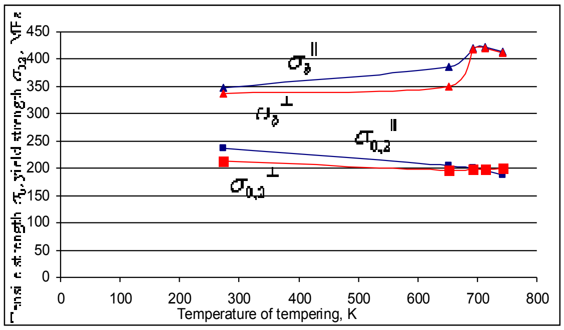

Figure 3 - Change of tensile strength and yield strength depending on quenching temperature: $\sigma_b^{\parallel}$, $\sigma_{0,2}^{\parallel}$ – tensile strength and yield strength of the samples cut along the extrusion axis, $\sigma_b^{\perp}$, $\sigma_{0,2}^{\perp}$ - tensile strength and yield strength of the samples cut across the extrusion axis.

Figure 3 shows the growth in tensile strength σ_b (sigma b), decrease of yield strength $\sigma_{0,2}$ while temperature quenching rises. Figure 4 shows the dependence of the relative elongation and toughness upon the quenching temperature.

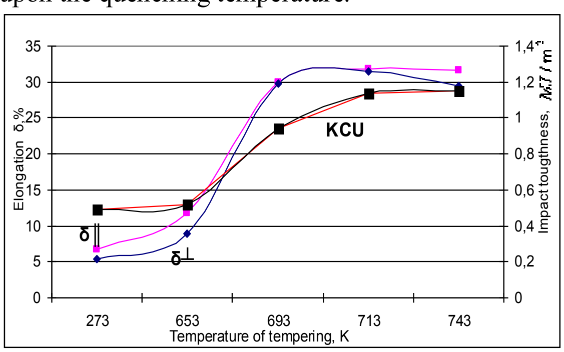

Figure 4 - The change in elongation and toughness as a function of the quenching temperature

Details of ductility and toughness increase with temperature quenching.

Figure 5 shows the curves of "engineering strength σ_i-engineering deformation ε_i" of the alloy samples quenched from different temperatures.

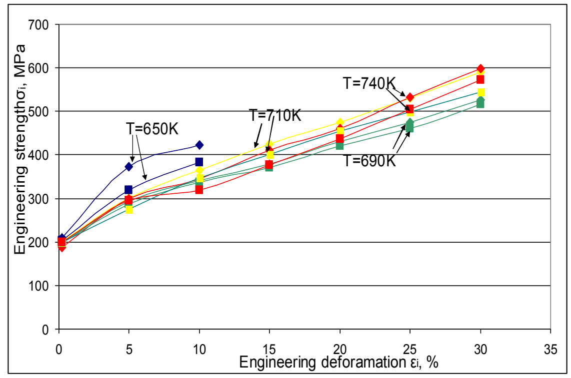

Figure 5 - Change the engineering strength from engineering deformation of alloy quenched from different temperatures.

As seen from these graphs, increasing the quenching temperature has an ambiguous effect on the character of the alloy hardening: the increase in the heating temperature from 650 to 690 K leads to a decrease in indicators of engineering strength, further increasing in temperature slightly increases and does not affect the nature of the curves.

Figure 6 shows the microstructure of the specimens in an equilibrium state, and after quenching from different temperatures.

As it follows from the microstructure in the equilibrium state in the alloy structure a substantial amount of dispersed phase is present. This is mainly β-phase, but large inclusions of magnesium silicide Mg_2Si also meet. The grain size is not equal, lays in interval 20-70 micrins and does not desapeared in process of heating.

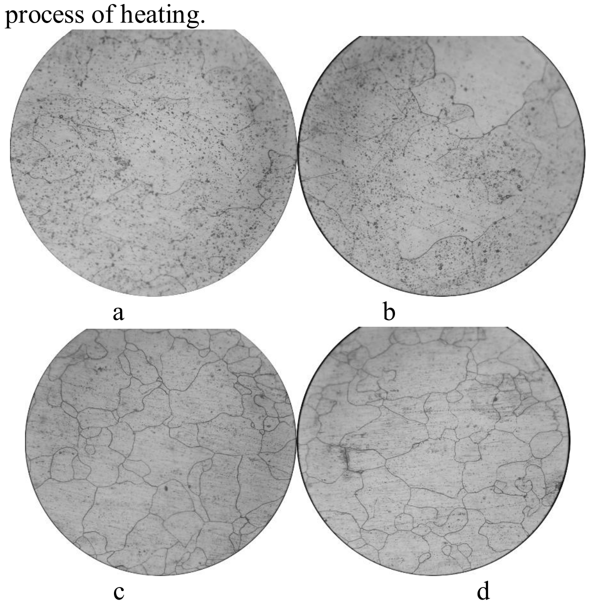

Figure 6 - The microstructure of the samples, x500: a - in the annealed condition, b, c, d - after quenching temperature 653K, 693K and 713K respectively.

4. Discussion

These results show that quenching efficiency increases sharply at temperatures above the 690K, while the high strength and plastic characteristics are stored before hardening temperatures of 740K. Solvus temperature of the alloy according to (Mondolfo L. F., 1976), is at 650K. At temperatures above the solvus line 40 ... 50 K (β-phase Al_8Mg_5 and other intermetallic phases is like Al_3Zr) almost completely transformed into α-solid solution. Often formula β (beta) - phase is as Al_3Mg_2 (Golovin I.S. et al, 2013), but it has a magnesium content of about 37.5% by weight, whereas in the phase of Al_8Mg_5 composition contains about 36 wt.% Magnesium that on Al-Mg diagram is located closer to the left and to the aluminum corner. Therefore it is more likely that in equilibrium with the solid solution is phase Al_8Mg_5.

Solidus temperature which bounds the area of a solid solution from top limit is at 800K. Heating to these temperatures can lead to a burnout of the structure and melting of the grain boundaries. Fixing by quenching the homogeneous solid solution is accompanied by a sharp increase of enough tensile strength and especially plastic characteristics - elongation and toughness (Avazkonandeh-Gharavol M.H. et al, 2014).

Quenching of the longitudinal and transverse specimens accompanied identical nature of the change properties. At temperatures above 690K quenching difference in properties is reduced and does not exceed 2%. The dispersion microstructure formed during crystallization of the alloy is grains of the solid solution of aluminum primary and secondary intermetallic compounds, such as Zn_2Al_3, $TiAl_3$, Al_8Mg_5, which provide improved processability of alloy (Liu Feng-xiang et al, 2009).

It is nessesary to note that uneven grain size, which is usual for hot extruded profiles, remains in microstructure of samples quenched from all choosen temperatures. As rule, the unevent grain leads to a low stampability of the flat workpieces. So in this case it's effect didn't observe.

Thus, the optimal in terms of a combination of high strength and ductility for extruded products made of alloy with a high content of magnesium is quenching from heat temperature 710 ... 740 K and water cooling with temperature 320...330 K. Mechanical properties after this mode of heat treatment are tensile strength - 410-420 Mpa, yield strength 185-200 MPa, elongation of 30-32%, the toughness of 1.15 MJ/m2, which exceeds similar characteristics of the alloy 5056 and is located at level of the low-carbon steel type A620, A622. The alloy of Al-10% Mg has high hardenability at cold deformation. This makes it possible to expose not only the semi-hardened tensile straightening but also significantly deform them in a cold state increase by providing strength characteristics of tensile strength to 530-550 MPa at a sufficient level of ductility (5.6% elongation). (21, 8, 15).

5. Conclusion

Studies have helped to identify the optimal mode of hardening high-magnesium alloy that keeps the optimal ratio of strength and ductility characteristics.

The microstructure of samples heat treated at these modes confirmed the physical picture of the structural transformations.

The results confirmed the possibility of thermal hardening aluminum alloy with high content of magnesium by quenching. Future studies related to the study of properties and structural transformations at the subsequent natural and artificial aging.

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