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EFFECT OF HEAT TREATMENT OF AL-7075-T6 INFLUENCE OF THERMO MECHANICAL EFFECT ON STRUCTURE AND PROPERTIES

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ABSTRACT

Aluminium alloy 7075 is widely used for the automotive parts that work under the conditions of dynamic stress and cyclical loads. Automotive parts made from this alloy have to maintain high impact strength and hardness. High mechanical properties are achieved by thermo mechanical treatment when fibrous macrostructure and effect of precipitation hardening are obtained. This work deals with the investigation of changes of macrostructure and mechanical properties of alloy 7075 under various conditions: after quenching and artificial ageing; after plastic deformation, quenching and artificial ageing; after complete thermo-mechanical treatment. The results obtained will be used for the development of manufacturing technologies of the automotive parts.

Keywords: *Aluminium, Alloy 7075, Precipitation Hardening, Automotive Parts*

1. Introduction

Some of the materials used for hot extruded automotive parts are light and strong aluminium alloys from 6XXX group. The main requirements for the alloy are sufficient plasticity for extrusion, high friction resistance in the slide pair with steel parts, ample strength and resistance to the dynamic strains. The most suitable aluminium alloys are wrought and heat treatable (treatment T6) ones. Al-Mg-Si alloy 7075 is the best choice for this purpose. Alloy 7075 (EN AW-6082) is a medium strength alloy with excellent corrosion resistance. It has the highest strength of the 6XXX group alloys. Also, alloy 7075 offers good weldability, brazeability, formability and machinability [1]. It contains only 2-3% alloying additives, thus its strength is lower comparing with duralumin [bauman], but plasticity and corrosion resistance are excellent. The principal alloying elements in Al-7075 are Si, Mg and Mn that play important role on structure and properties of the alloy [2]:

Silicon solution in aluminium is limited: up to 1.56% Si at 577^{o}C temperature and <0.1% Si at room ambient temperature. In the Al-Si alloys these two components compose two different phases: aluminium matrix and silicon crystals. Silicon crystals are glaring, rigid (HV608) and brittle, so Si (as Fe, also) amount may be limited in the aluminium alloys. When aluminium is alloyed by other components as Mg, Mn or Cu, silicon composes disperse intermetallic compounds, consequently, strengthening alloy during ageing. Magnesium dissolves in aluminium up to 17.4 wt.% at 450^{o}C temperature, and about 1.4 wt.% at room temperature. During aging of Al-Mg-Si alloys, phase Mg_2Si forms giving a reinforcing effect of alloy.

Manganese is almost insoluble in aluminium. With other components Mn forms disperse intermetallic compounds Al_6Mn, α(Al-Si-Mn), Al_6(MnFe) and $Al_{10}Mn_2Si$. Disperse phase Al_6Mn and α(Al-Si-Mn) increase temperature of recrystallization of Al-Mg-Si alloys and aggravates secondary recrystallization (the growth of giant grains in the structure). Owing to the presence of Mn, higher strength is achievable after forging and heat treatment. Other alloying elements such as Fe, Cu, Zn, Cr, are inserted in smaller quantities.

Increasing demands on such materials in building, aircraft and automotive industries have resulted in increasing interest and research of many scientists from many countries [3-8]. The most

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interesting areas of the research are related with the investigation of structure evolution under heat treatment [9-12] as Al -7075 is age-hardenable alloy related with the precipitation of intermetallic compounds Mg2Si, Al6Mn, Al6(Mn,Fe), Al10Mn2Si. Therefore, the well-chosen heat treatment or thermo mechanical treatment as well may become a cornerstone on purpose to obtain eligible mechanical properties of the part.

During thermo mechanical treatment of aluminium alloys some specific structure defects – coarse recrystallized areas may occur [13, 14]. Recrystallized areas are mostly observed in the surface layers that are in direct touch with the dies and/or in regions where local changes of plastic deformation take place. Recrystallized layers and areas in forgings have negative effect that the boundary between two different structures possessing remarkably different mechanical, fatigue and corrosion properties, is formed. It was found [13] that recrystallized structure, in comparison with the unrecrystallized one, has lower values of ultimate strength (approximately by 70-90 MPa) and higher ductility (by 10%). Furthermore, fatigue properties were obtained lower by one order in the case of recrystallized structure.The susceptibility to the formation of those structures depends on forming and heat treatment parameters and on the alloy type as well.

Our work was mainly focused on improvement of manufacturing technologies of Al-7075 automotive parts, for the purpose to obtain higher mechanical properties and fibrous, not recrystallized microstructure.

2. Material and methodology

Material used for the experimentation is extruded profile from wrought aluminium alloy 7075 in T4 condition with chemical composition listed in Table 1. Alloy 7075 is used for manufacturing of automotive parts and before forming and heat treatment has to maintain requirements presented in Table 2.

Table 1. Chemical composition of EN AW-7075-T-6.

Element, wt.%								
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.3	0.2	1.53	0.25	2.5	0.20	5.45	0.16	Rem

Table 2. Mechanical properties and requirements to aluminium extruded profile from alloy EN AW-7075-T6 at 20°C temperature

R_m, MPa	$R_p0.2$, MPa	Elong.% 50mm	Hardness HB
Specified values:			
Min.	Min.	Min.	Min.
202	112	12	-
Measured values:			
230-261	123-148	17-23	-

Several tests were made at the laboratory for the evaluation of hardness HRB, U-notched Charpy impact strength, macro and microstructure of such treated semi manufactures. Hardness of specimens was determined by measuring HRB values at three places of each specimen by Rockwell meter TK-2 under 300 kgf loads. Then, HRB units were calculated to HB system. Impact strength of the material was determined by Charpy impact testing machine using U-notched specimens made from semi manufactures (Fig. 1).

For the observation of macro and microstructure, cross-cuts were made from critical places of the investigated semi manufactures (Fig. 2) after thermo mechanical treatment. Cross-cuts were cold mounted by the resin Technovit 4071, then grinded, polished with dough of chromium oxide and soup, and etched in 0.5 % HF water solution. The macro and microstructure was examined by the laser micro-analyzer LMA10 Carl Zeiss with video camera YCH15.

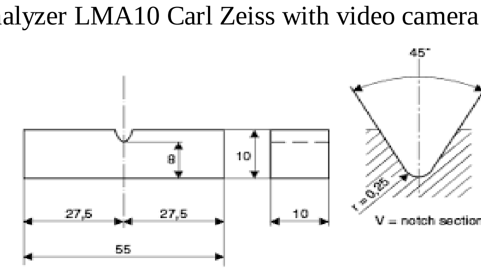

Fig. 1. U-notched sample for Charpy impact testing

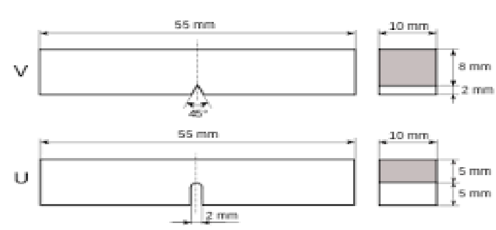

Fig. 2. Location of sample for the cross-cut

3. Results and discussion

3.1. Evaluation of structure and mechanical properties of forgings after applicable thermo mechanical treatment

Some samples were manufactured from the billets after thermo mechanical treatment as following:

- Heating of an ingot at 500°C temperature for 1 hour in the chamber furnace
- Double-hit forging
- Heating for hardening at 540°C temperature for 1 hour in the chamber furnace
- Water quenching in 25°C temperature water
- Artificial ageing at 160°C temperature for 12 h in the shaft furnace

At the first, the ingots were heated at 500°C temperature and then hot forged by double-hit. After forming, the die forgings were water quenched immediately for the purpose to maintain press-effect (the fibrous structure specific for the forged item) (Fig. 3). As the structure didn't show any origins of recrystallization, after artificial ageing the hardness HB was obtained too low – just 91 units. That showed that 500°C was not sufficient temperature of quenching.

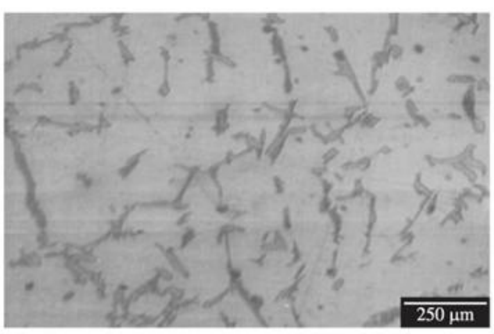

Fig. 3. Fibrous structure of alloy 7075 after heating at 500°C, double-hit forging, immediate water quenching and artificial ageing for 12 h at 160°C

Some scientific articles [2, 15] propose that the optimal temperature of quenching for the alloy 7075 is in the range of 515-540°C. The required hardness HB (~110-120) was obtained when the die forgings were water quenched from 535°C and artificially aged, but the microstructure of cross-cuts was fully recrystallized presenting the coarse grains (Fig. 4, 5). Although the recrystallization had not any significant influence on hardness of the alloy in our work while some scientific articles deal with converse data [13]. It is known that recrystallization reduces impact strength and especially fatigue lifetime under the multi-cycle loads [2, 13, 16]. Thus, the structure of the alloy without any recrystallization (retained press-effect) has to be pursued in order to improve these mechanical and fatigue properties.

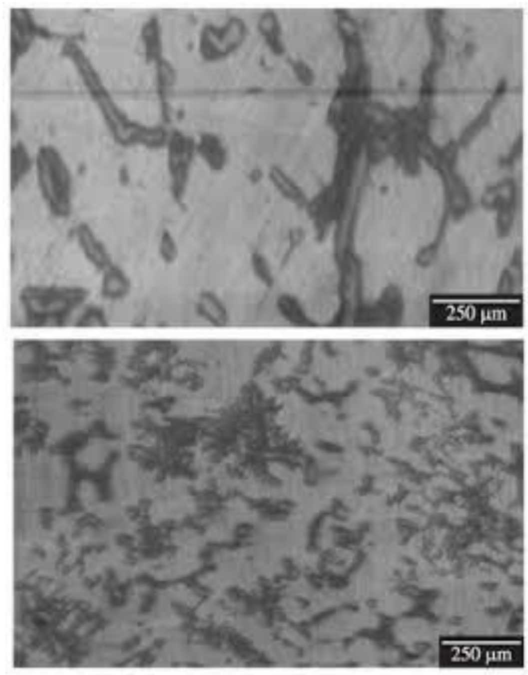

Fig. 4. Coarse crystals as the result of the secondary recrystallization at the cross-section of die forging

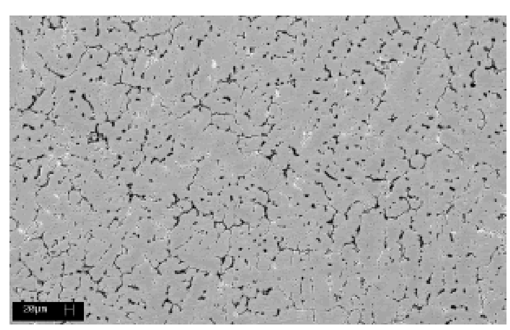

Fig. 5. Recrystallized macrostructure after double-hit forging at 500°C, repeated heating at 540°C for water quenching and artificial ageing at 160°C for 12h. Hardness HB 112, U-notched Charpy testing ISO-U=29.4 J/cm^2

On purpose to obtain stabile mechanical properties after quenching and artificial ageing (T6), it is necessary attain sufficient dissolution of intermetallic compounds in matrix (this can be varied by the temperature and duration of heating) and fast cooling that the alloying elements dissolved in aluminium wouldn't be able to precipitate from solid solution. The curves at Fig. 6 show increase of hardness of aged samples the duration of heating was extended, especially when the die forgings were quenched from lower temperatures. Outside time, when sample was carried from furnace to die, if it has not exceeded 20s, didn't show any influence on hardness of samples. Delayed a little longer, hardness of specimens was decreased significantly.

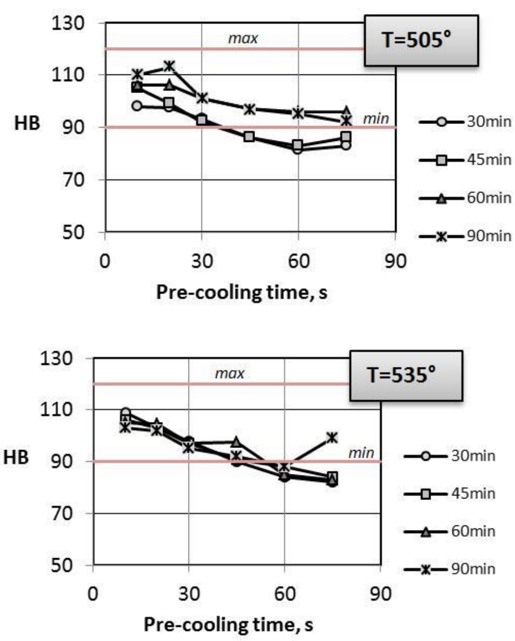

Fig. 6. Influence of quenching temperature, heating duration and pre-cooling time on hardness of alloy 7075 after artificial ageing (after T6 treatment).

3.2. Investigation of microstructure and properties of quenched die forgings after hot extrusion and artificial ageing

The temperatures of quenching and hot forging of alloy 7075 are similar, thus the high-temperature thermo-mechanical treatment could be practised. The ingots were heated at 515-540°C temperature, double-hit forged and quickly water quenched. Such treatment simplifies technology of manufacturing, saves labour and energy expenditure, furthermore, impact strength increases several times.

Quenching from lower temperatures allowed avoiding recrystallization, i.e. press-effect remained, when die forgings were up to 0.25kg of weight (Fig. 7). Recrystallization may proceed at separate locations of the die forgings when their pre-cooling time at cold die during deformation process becomes insufficient because of larger weight (Fig. 8). However, these recrystallized grains were very small and had no significant influence on quality of product. Forming of massive forgings at high temperatures (530-540°C) produced considerable secondary recrystallization, especially at the external surfaces, where giant crystals had grown (Fig. 9). Before deformation, in order to avoid recrystallization, hot ingot was pre-cooled intensively for 8-10s for temperature decrease to 500-480°C.

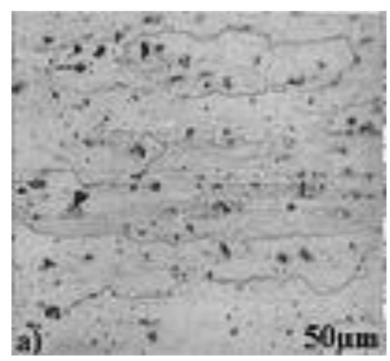

Fig. 7. Fibrous macrostructure after forming and quenching from 515°C temperature, and artificial ageing (T6). Hardness HB 98; U-notched Charpy testing ISO-U=39.6 J/cm^2

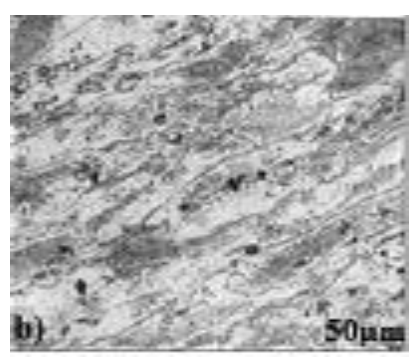

Fig. 8. Fibrous macrostructure at cross-section of forging after quenching from 520°C and artificial ageing (T6). Small recrystallized grains are visible at the surface. Hardness HB 97, U- notched Charpy testing ISO-U=40.5 J/cm2

Quenching from high temperatures without pre-cooling before extrusion may result cracks coming at the surface of forging, especially during cooling in cold water (Fig. 10). Impact strength of unrecrystallized structure, in comparison with the recrystallized one, was obtained higher by 25% and more, in some cases even up to 50%.

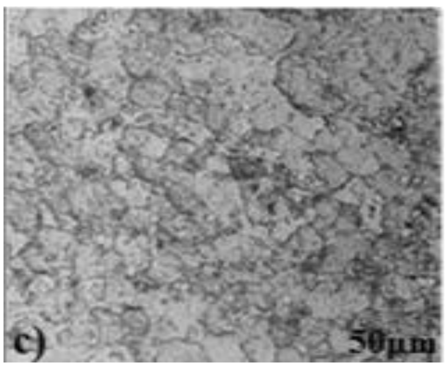

Fig. 9. Fibrous microstructure at cross-section of forging after quenching from 535°C and artificial ageing (T6). Coarse crystals are detected at the surface. Hardness HB 104, U-notched Charpy testing ISO-U=42.2 J/cm^2

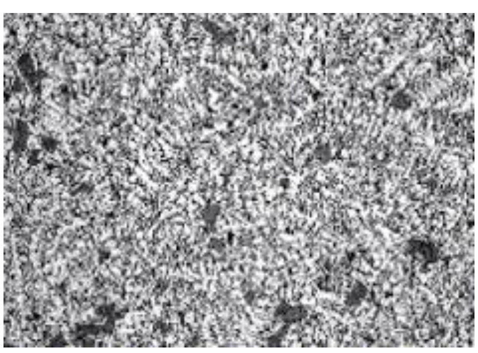

Fig. 10. Surface of forging after 540°C heating, double-hit deformation, quenching in water of 13°C and ageing at 160°C for 12 hours

4. Conclusions

Double-hit forging and following water quenching ensures press-effect – fibrous macrostructure without recrystallization and with good mechanical properties of items made from alloy 7075.

Heating of die forgings at temperatures over 500°C between the first and the second die hits eliminates press-effect – recrystallization proceeds with following growing of giant crystals. This causes decrease of mechanical properties.

High-temperature thermo-mechanical treatment is possible for alloy 7075 ingots and has to be following: Heating up to 515…540°C; Pre-cooling before hot deformation for 10-12s till 480-500°C temperature decrease; Double-hit forging and immediate water quenching; Temperature of water has to be 20…60°C. Lower temperature of water may cause cracks and deformations of forgings; Artificial ageing is the last operation of high-temperature thermo-mechanical treatment.

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