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Microstructure evaluation of the Al-Ti alloy with magnesium addition

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ABSTRACT

Purpose: Effects of magnesium additions to Al alloy with 2% Ti addition on the microstructure, phase morphology and distribution and mechanical properties were investigated. Here are presented mainly microstructure changes after solution heat treatment concerning mainly grain uniformity and intermetallic phases of the aluminium – titanium alloy with a content of 2 and 4 % of magnesium addition. The purpose of this work was also to determine the solution heat treatment conditions of the investigation alloys.
Design/methodology/approach: The reason of this work was to determine the heat treatment parameters influence, particularly SHT temperature and time onto the changes of the microstructure of the investigated material, as well to determine which intermetallic phases occur after the heat treatment performed, and how is the particles morphology in as cast state compared to structure after heat treatment.
Findings: After solution heat treatment for 4 hours the structure changes in a significant way. The grains are larger and no more uniform as in the as cast state. The most stable intermetallic in the Al-Ti system is the Al_3Ti phase. The solution heat treatment time should be greater than 4 hours to ensure a proper solution of titanium and magnesium in the Al-α solid solution.
Research limitations/implications: The investigated aluminium samples were examined metallographically using optical microscope with different image techniques, scanning electron microscope and also analyzed using a Vickers micro-hardness tester, also EDS microanalysis was carried out.
Practical implications: As an implication for the practice an alloy can be developed with increased properties, which could be of great interest for the automotive or aerospace industry. There are existing many different investigation areas and the knowledge found in this research shows one of interesting investigation direction.
Originality/value: The combination of light weight and high strength achieved in the Al-Ti alloys is very attractive for aerospace and automotive industries. Addition of magnesium into the Al-Ti alloy could help also to reveal the existence new unknown phases.
Keywords: Casting; Heat treatment; Aluminium alloys; Magnesium

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1. Introduction

As all materials, aluminium alloys have an advantages and disadvantages. Their advantages include first of all: low density, relatively high specific strength, good castability, and good weldability in a controlled atmosphere, good corrosion resistance.

The most important disadvantages are: low Young's modulus, limited possibilities of cold workability, relatively low hardness, limited strength and creep resistance at elevated temperatures, high chemical reactivity, in some cases, limited corrosion resistance. The titanium-aluminium binary system provides a model for solution strengthening. In addition, it is the prototype of technical α alloys, as well as the α components of α+β alloys [1-8].

Aluminium is the most widely used alloying element in titanium-based alloys for example in the automobile or sport industry (Figs. 1a and b). It is the only common metal that raises the beta transus temperature and have large solubilities in both the alpha and beta phases. On the basis of theoretical considerations, deviations may arise from the fact that size parameters gradually reach the dimensions of some characteristic lengths related to the original deformation mechanism, e.g. the width of a dislocation source in the case of glide deformation. Under these circumstances, additional constraints may complicate or impede single steps of the formerly prevailing deformation mode, thus contributing to changes in the mechanical behaviour [9-18].

a)

b)

Fig. 1. Elements for the car and sport industry produced form the Al-Ti alloy, a) car wheel, b) bicycle equipment

The possibility of establishing thermally stable fine-scale dispersion of secondary phases in the as-quenched structure or during subsequent heat treatment offers potential improvement in mechanical properties of alloys via this route. Al-based alloys are particularly suitable to be developed by solution heat treatment and ageing, but only nine elements show appreciable solid solubility (greater than 1 at. %) in Al and only five of these have been exploited commercially [19-24].

Magnesium was used as the alloying additive, because it:

- the aspect ratio (length/width) of precipitates changed to higher values (e.g. above 3),
- reduces agglomeration of phases particles,
- increases porosity.

Apart from the alpha and beta phases, the presence of Ti_3Al phase (known as α2) and TiAl (gamma) intermetallic phase in the titanium-aluminium binary system is also noteworthy (Fig. 2). Both phases are of great technical importance (e.g., titanium-aluminide alloys, important for high-temperature applications). Also the occurrence of small amount of the magnesium titanium $Al_{18}Mg_3Ti_2$ phase could be expected (Fig. 3). Of great importance is also nano- and submicrocrystalline alloy microstructure characterised by high values of strength and hardness. Many studies have addressed the question of to what can be performed practical to implement this Hall-Petch behaviour, entailing a correlation between yield strength (y) and grain size (d) according to this dependence [25-29].

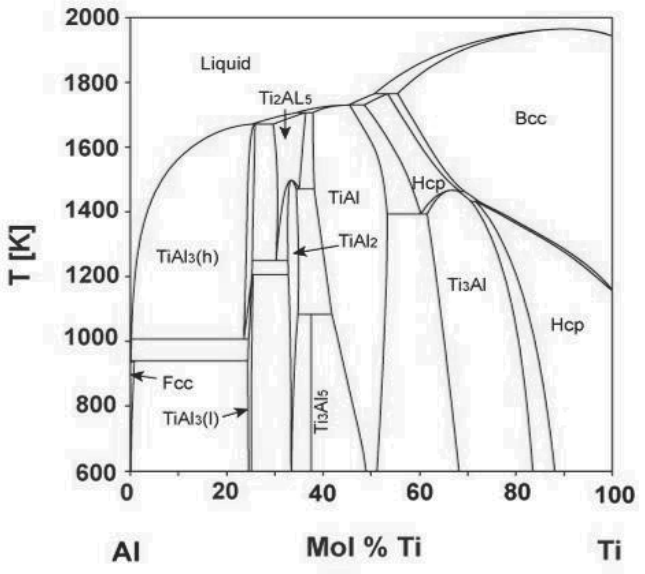


Fig. 2. Al-Ti phase diagram

In this work the $TiAl_3$ phase is of great interest which is an ordered structure based on the hexagonal close-packed alpha phase. A unit cell of the DO19 structure is composed of four regular HCP cells supported by covalent-like directional bonds connecting the titanium and aluminium atoms. [30-34].

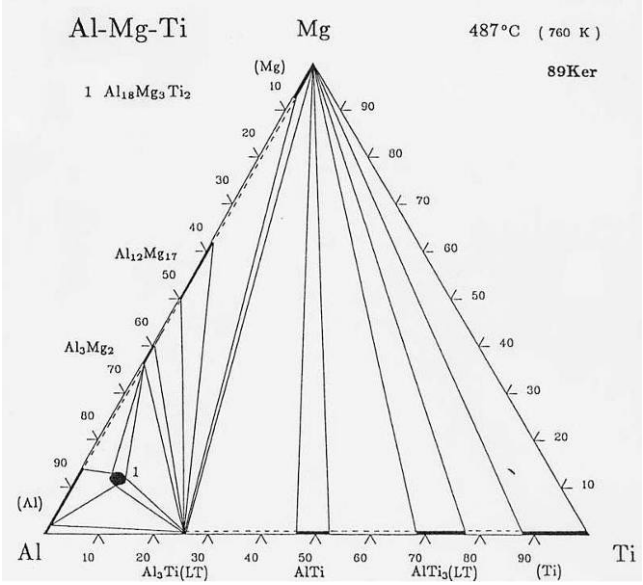


Fig. 3. Al-Ti-Mg ternary phase diagram

2. Experimental procedure

The alloys used for this work were produced in the SINTEF laboratory, with the basic components of Al 99.99%, Ti 99.99%, Mg 99.99% and basic alloy 10 Ca Al (R2516), incl.: Ca 9.33%, Fe 0.08%, Si 0.01%, Mg 0.06%, Sr 0.014% (wt%) like impurities.

It is an experimental aluminium-titanium alloy with magnesium addition which was investigated in this work. The exact chemical composition is showed in Table 1. Using a properly adjusted (Fig. 4) electro-resistance furnace all elements with the calculated and measured amount of the additives were melted in a ceramic crucible and then melt into a carbon form, witch was cooled in air in a water-cooled aluminium block. in the furnace a controlled protective argon atmosphere was used to avoid contamination and oxidation of molten aluminium and additives.

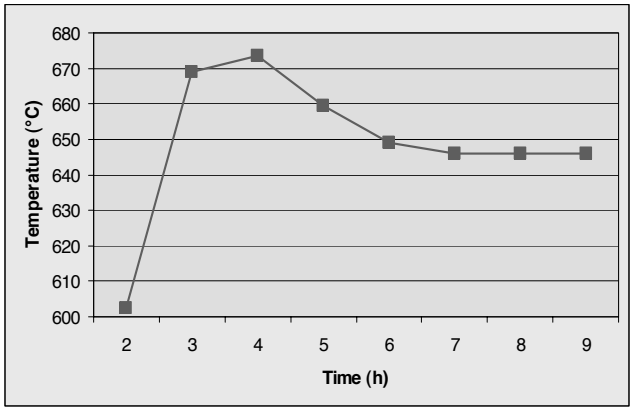


Fig. 4. Furnace temperature adjustment diagram

Samples with masses of approximately 120±20 g were melted in a carbon mould. Than the mould with liquid metal was located in a water-cooled aluminium radiator. Cooling rate during the solidification was in range 1.6-2.5°C/s - depending of the kind of alloy investigated. Samples for analysis of the microstructure were cute close to the centre of the cast samples. The cross sections of the specimen were ground, polished (used slurry up to 1 µm) and anodized in HBF4 acid water solution for grain, microstructure and phase observation. The microstructure of the samples ware observed by an light microscope provided by Richter-Jung, model MEF3 LOM computerised with special KS 300 software.

It was very important to keep a high purity of the raw materials. It was chosen a 99.99% Al and 99.99% Ti master alloy which was the highest purity industrially available. Special care has also been taken in the melting and casting process: an alumina and a graphite crucible made from a high purity material was used, together with argon of 99.9999% purity to avoid contamination by gas elements, especially hydrogen.

For identification of the phases Scanning Electron Microscope equipped with EDS detector, Transition Electron Microscope (TEM) 200Cx supplied by Joel was used. The sample for TEM were ground mechanical to below a value in the range of 25 to 50 µm in thickness and 3 mm disk-diameter, and than thinned electrolytic at 40-50 volt, with 3 ampere current in T4 electrolyte for 20 s.

Table 1.
Chemical composition of the investigated alloys in wt. %

Alloy	Al	Ti	Mg
AlTi2Mg2	96	2	2
AlTi2Mg4	94	2	4

Qualitative and quantitative assessment of the chemical compositions of the phases was investigated using Philips XL 200 scanning microscope with energy dispersive spectrometer. For each phase about 8 separate spot measurements were made and also statistical values like mean values were calculate.

The microhardness was measured using a HV hardness testing machine supplied by Zwick, with $HV_{0.05}$ scale. The microhardness was measured in 8 places and the a mean value was calculated.

3. Results and discussion

3.1. Microstructure characterization of the alloy in as cast state

The microstructure investigations reveals that after casting in the as-cast the alloy microstructure is non-uniform with areas of very small grains and some big grains inside (Fig. 5). There is a small amount of the Al_3Ti phase. This Al_3Ti phases particles are formed in localized regions of the matrix, and they do not

suppress the growth of directional pores in the other regions. Spherical pores surrounded by equiaxed peritectic microstructure and homogeneously distributed Al_3Ti phases are formed, because the primary α -Al and Al_3Ti phases probably prevent the growth of directional pores. These Al_3Ti phase particles could be observed in the optical micrographs presented on Figs. 6a-c. Titanium phase Al_3Ti showed on this figures is present in form of bulk particles over the whole structure, as well in form of longitudinal needle in case of both investigated alloys AlTi2Mg2 and AlTi2Mg4.

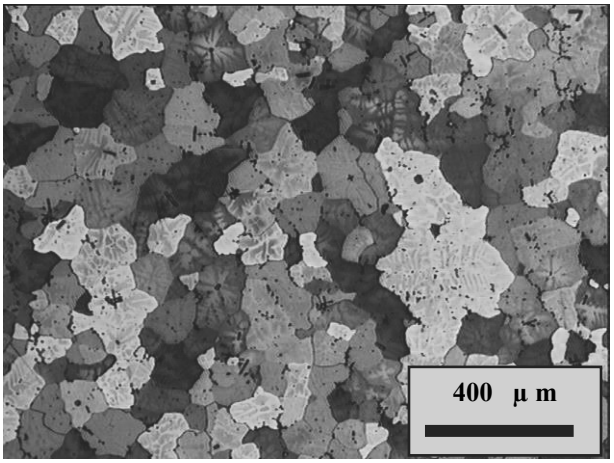


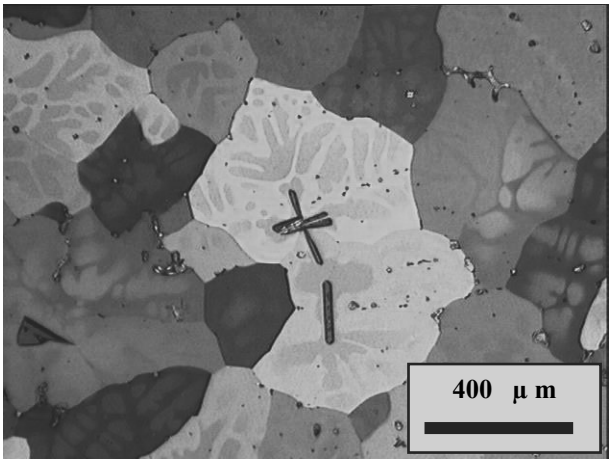
Fig. 5. Microstructure of the Al-Ti-Mg alloy in as cast state

3.2. Solution heat treatment performed on the AlTi2Mg2 and AlTi2Mg4 alloy

Heat treatment of the investigated alloys includes two following steps: solution heat treatment and artificial aging. In this paper there is especially investigated the microstructure after properly performed solution heat treatment The heat treatment was performed in an electrical resistance furnace, and the samples were cooled in water. Temperature of solution heat treatment was determinate experimental, using a pair of thermocouples place inside the furnace. The applied SHT time was 24 hours.Artificial aging was performed in 180°C for 30, 60, 120 and 240 min also in an electrical resistance furnace, after this operation samples were cooled in air slowly.

To establish the highest possible solution heat treatment temperature, the samples were heat treated also in higher temperature above 600°C until small areas with partial melting places were detected. So in finally a temperature of 580ºC and 575ºC - Table 2 - was determined as the highest possible. Furthermore structural changes were find in samples with different time of solution heat treatment compared to the structure of as cast alloy. Generally grain growth can be state according to the selected time.

a)



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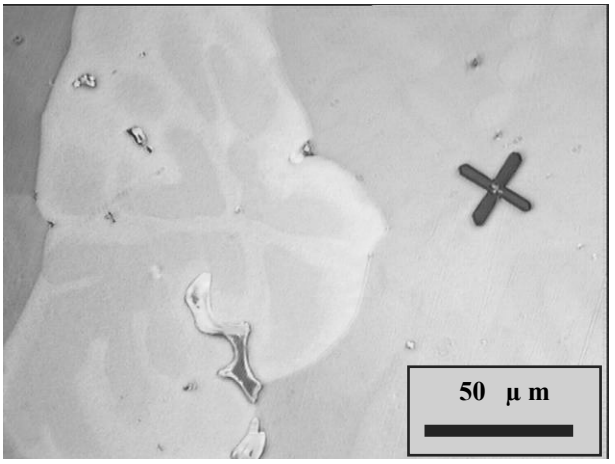

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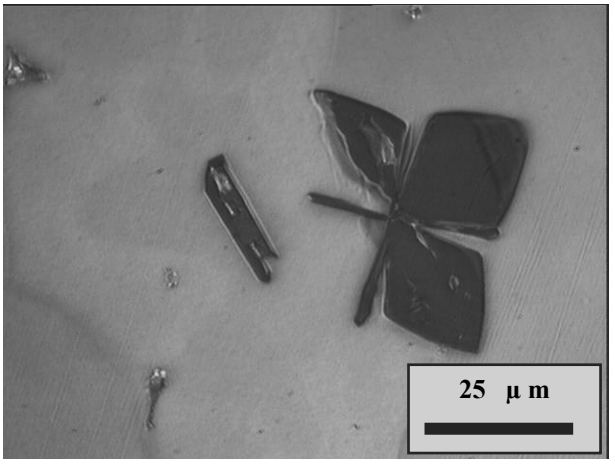


Fig. 6. Microstructure of the Al-Ti-Mg alloy in as cast state, a) dendritic character of the grain chemical composition, b) longitudinal Al_3Ti phase, c) bulk shaped Al_3Ti phase

Table 2.
Temperature applied for the of solution heat treatment for the investigated alloys

Alloy	Solution Heat Treatment temperature, °C
AlTi2Mg2	580±1
AlTi2Mg4	575±1

Form the investigate alloys also hardness was measurement was performed in the Vicker $HV_{0.05}$ scale. The results are presented in Table 3 for the as cast material as well for solution heat treatment performed for 4 hours.

Table 3.
Vickers microhardness $HV_{0.05}$ measurements results of the investigated AlTi2Mg2 AND AlTi2Mg4 alloys

Heat treatment / Alloy	Hardness, $HV_{0.05}$	
	As cast state	After SHT for 4 hours
AlTi2Mg2	52±1	27±1
AlTi2Mg4	58±1	52±1

In general the microstructure of the AlTi2Mg4 reveals smaller grains compared to the AlTi2Mg2 alloy (Fig. 11 and Fig. 14). The chemical composition dendrite-like non-homogeneity inside the grains is also less visible in case of the AlTi2Mg4 alloy (Figs. 12 and 15). For both of the alloys there is the Al_3Ti phase discovered, (Figs. 7-10), but for the AlTi2Mg2 alloy (Fig. 13) it is present in form of bulk shaped form, where as for the AlTi2Mg4 is appears mainly in the bulk and longitudinal needle form (Fig. 16).

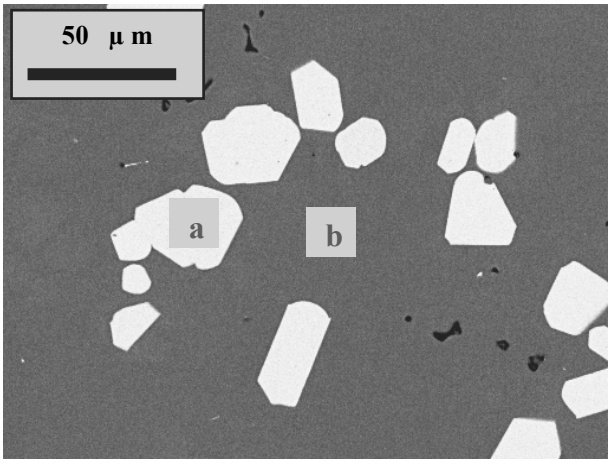
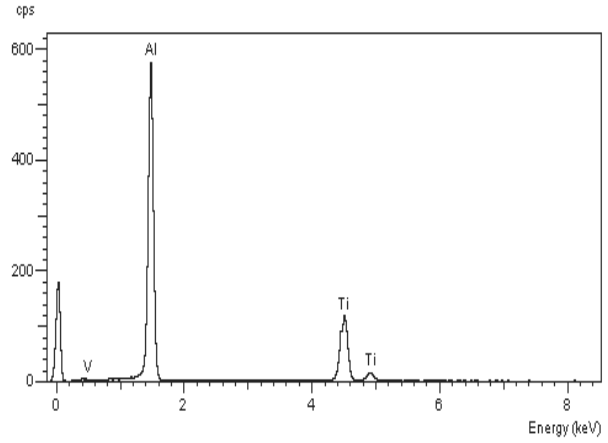


Fig. 7. SEM microstructure for EDS microanalysis performed on visible phase particles AlTi2Mg2 alloy

a)



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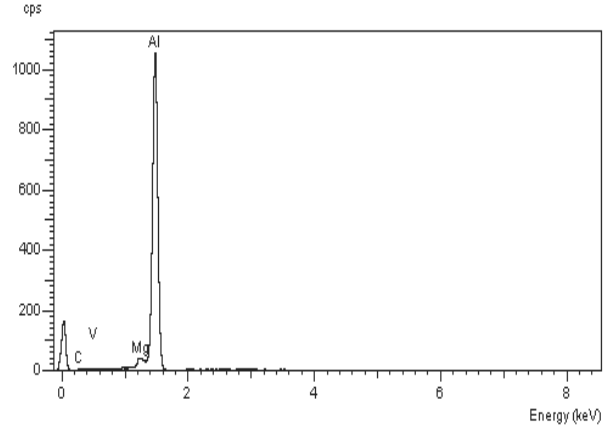


Fig. 8. EDS microanalysis performed on the marked places (a, b) on Fig. 7, AlTi2Mg2 alloy

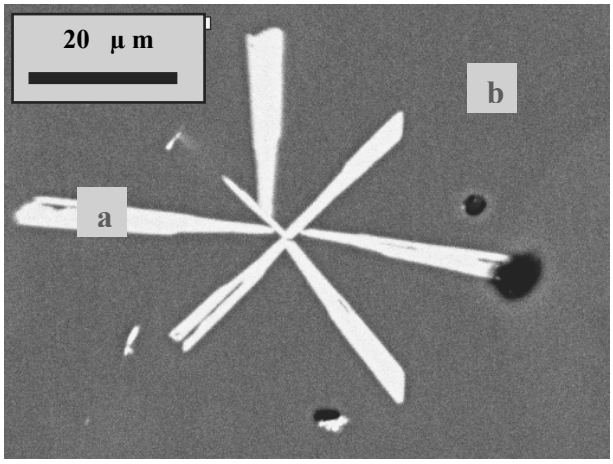
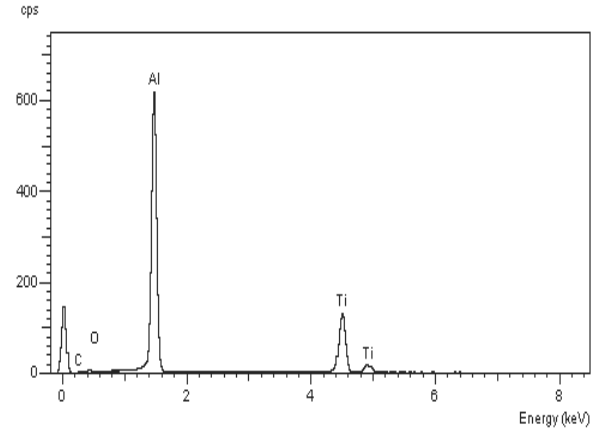


Fig. 9. SEM microstructure for EDS microanalysis performed on visible phase particles AlTi2Mg4 alloy

a)



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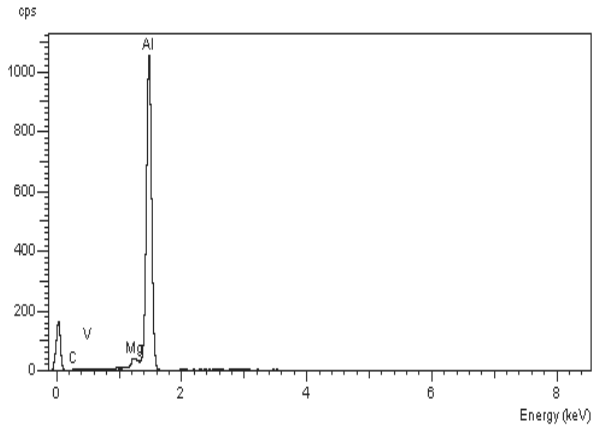

Fig. 10. EDS microanalysis performed on the marked places (a, b) on Fig. 9, AlTi2Mg4 alloy

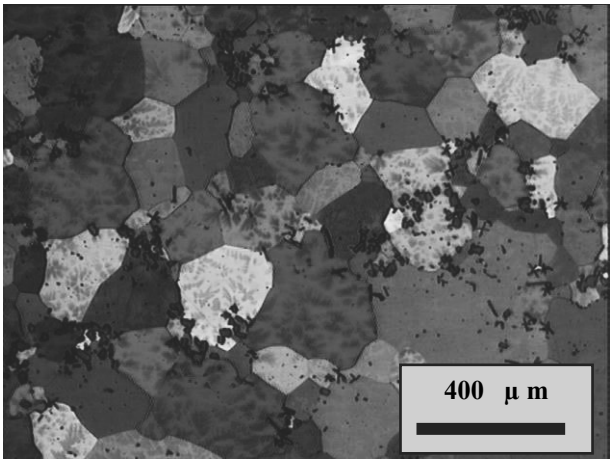

Fig. 11. Grain size of the AlTi2Mg2 alloy after SHT in 580ºC for 4 h

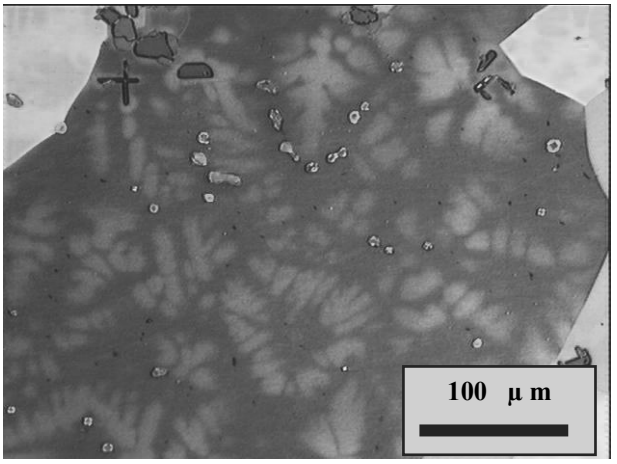

Fig. 12. Differences in chemical composition in a grain of the AlTi2Mg2 alloy after SHT in 580ºC for 4 h

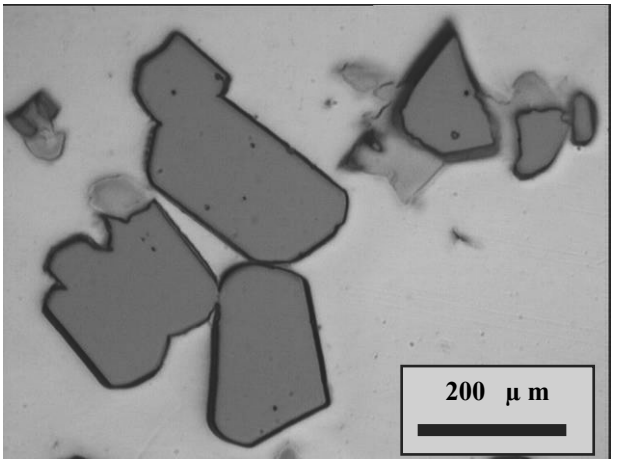

Fig. 13. Al_3Ti phase morphology, AlTi2Mg2 alloy after SHT in 580ºC for 4 h

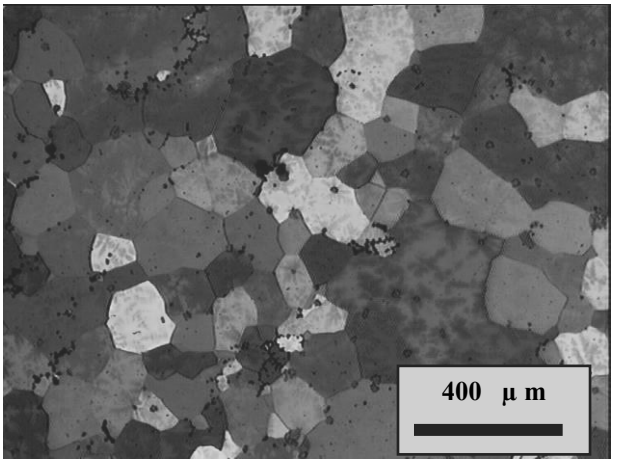

Fig. 14. Grain size of the AlTi2Mg4 alloy after SHT in 575ºC for 4 h

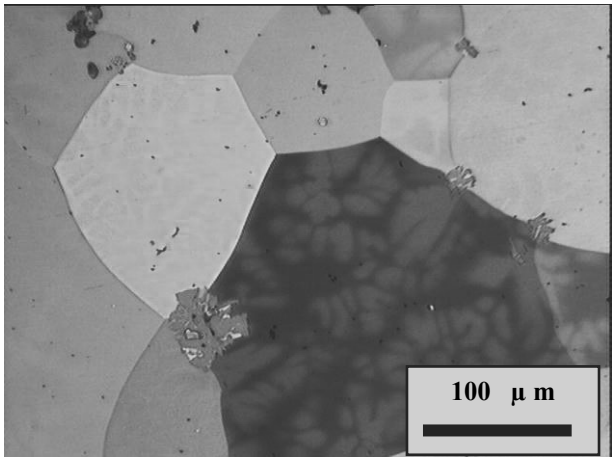

Fig. 15. Differences in chemical composition in a grain of the AlTi2Mg4 alloy after SHT in 575ºC for 4 h

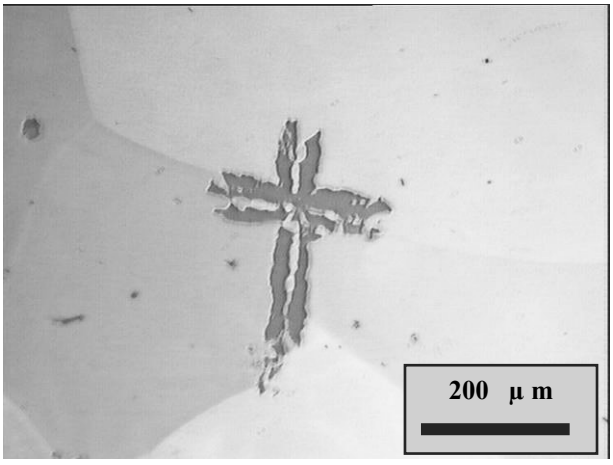

Fig. 16. Al_3Ti phase morphology, AlTi2Mg4 alloy after SHT in 575ºC for 4 h

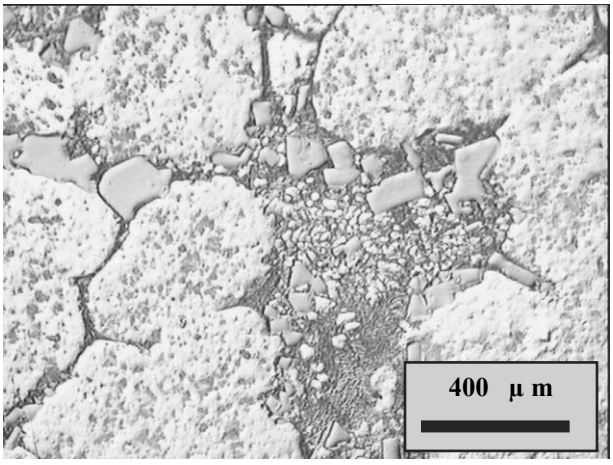

Fig. 17. Partially melting areas

4. Conclusions

It could be found on the basis of the microstructure investigations that directly after casting the as-cast alloy is non-uniform with areas of very small grains and some big grains inside. After solution heat treatment at the temperature of 580ºC (AlTi2Mg2 alloy) and 575ºC (AlTi2Mg4 alloy) for 4 hours the structure changes in a way, that the grains are larger for both alloys (Figs. 11 and 14) and no more uniform as revealed in the as cast state. This process is continuing also for a longer solution heat treatment time. Both in the as cast state and after SHT process the Al_3Ti phase can be observed. Wit a higher SHT temperature - when partially melting areas occur (Fig. 17) as well with a longer SHT time the Al_3Tiphase is growing up and breaking up in smaller parts. With a higher temperature a small amount of titanium (coming from the particles) is going into the solution (Al- matrix).

This process is confirmed with the hardness measurements where after 4 h solution heat treatment 27 $HV_{0.05}$ (AlTi2Mg2 alloy) and 52$HV_{0.05}$ (AlTi2Mg4 alloy) is measured, compared to 58 and 52$HV_{0.05}$ respectively. So the hardness value decreases for this alloy below the value of as-cast alloy (Fig. 18). But with an increase of the magnesium content ten hardness increases, that could be a reason for further investigations of this alloy with a higher Mg content. The reason for that can be, that the chemical composition gradient inside the grain changes and so the strengthening effect decreases.

We can conclude also that:

- The most stable intermetallic phase in the investigated Al-Ti system is the Al_3Ti phase,
- A proper solution heat treatment time of 4 hours is to short for maximising the mechanical properties of these alloys.

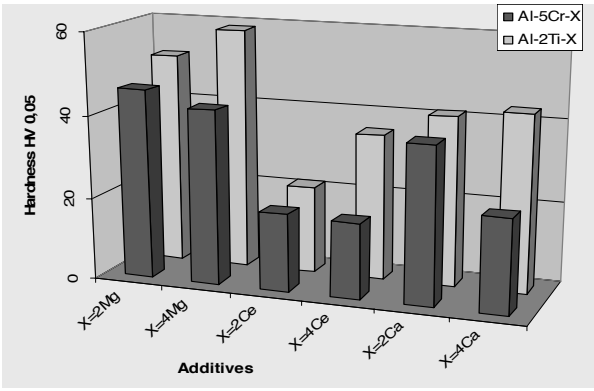

Fig. 18. Hardness measurements results of the alloys with magnesium, cerium and calcium addition

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