STRUCTURE OF NEW AL-SI BASED RQ SYSTEMS WITH POTENTIALLY ENHANCED STIFFNESS

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1. Introduction

Amorphous and nanocrystalline metallic systems prepared by rapid quenching of melt are interesting for many unique properties. Mechanical properties are among the most important ones. Rapid quenching of metallic melt can enhance mechanical properties of material, compared to metal alloys prepared by conventional metallurgy. Aluminium as one of most accessible light-weight metals has wide range of applications as construction material. Alloying aluminium with another element can significantlyimprove mechanical properties. Reasonable choice for alloying element in terms of sustaining light-weight nature of the material is silicon. Dissolving silicon in aluminium can be achieved, even with the aid of rapid quenching, only up to few weight percent. Increasing the content of dissolved silicon is possible by adding other alloying components. Candidates with respect to low specific mass are transition elements of 4^{th} period (from scandium to zinc).

In our experimental study, we have chosen alloying of Al-Si with transition elements (T) iron, cobalt and nickel. Composition of the investigated systems was $Al_{80-x}T_xSi_{20}$ where T = Fe, Co, Ni and x = 0, 5 and 10.

2. Experimental details

Rapidly quenched ribbons consisting of Al-Si, Al-Fe-Si, Al-Co-Si and Al-Ni-Si have been prepared by the planar flow casting (PFC) technique. During PFC, the melt is pressed by gas pressure through a nozzle on a surface of a fast rotating copper wheel. This allows the melt to solidify in a veryshort time of few μs. Final product obtained this way is a 20-40 μm thick amorphous, or in some cases nanocrystlline or polycrystalline ribbon with widths ranging from few mm to tens of mm. This structure can be further heat treated, while observing its physical properties. Changes in physical properties such as relative electrical resistivity and heat evolution are indicators of ongoing phase transformations. Structural properties before, during and after heat treatment can be for example observed by X-ray diffraction,transmission electron microscopy (TEM) or electrical resistivity measurements.

Change of resistivity of the ribbons was measured during linear annealing. Relative resistivity was acquired using AC resistivity bridge (Linear Research LR-100).Samples were heat treated in planar furnace with high spatial uniformity of temperature in argon atmosphere.

Content of various phases in samples was examined using X-ray diffraction. Samples have been examined in as-cast state or after heat treatment using Bruker D8 Advance powder diffractometer with Cr K-alpha radiation.

Microstructure of samples was investigated using transmission electron microscopy (JEOL 2000FX at 200 kV). Electron diffraction was used to determine phases present in the as-quenched state or after heat treatment.

3. Results

After cast, phase composition was determined using X-ray diffraction. Figure 1a.shows diffraction patterns of the investigated Al-Fe-Si, Al-Co-Si, Al-Ni-Si and Al-Si alloys in as-quenched state. Alloy of Al-Si with composition $Al_{60}Si_{40}$ (1), that was used as reference, shows mainly content of fcc-Al and Si.

By adding 5 at.% of transition element, the content of Si phase was significantly decreased. Phase analysis of $Al_{75}Co_5Si_{20}$(2) shows content of mainly fcc-Al and Si phases with minor content of various Al-Co and Al-Si phases, such as $Al_{0.52}$ $Co_{0.48}$, $Al_{0.96}$ $Co_{1.04}$ and $Al_{3.21}$ $Si_{0.47}$.Rather interesting result have been obtained for $Al_{75}Fe_5Si_{20}$ alloy (3), where aside from fcc-Al phase, Si phase and $Al_{3.21}Si_{0.47}$ complex Al-based phases [1] were detected.

With increasing content of transition element to 10 at.%, phase composition becomes more simple and the content of amorphous phase is increasing as demonstrated in Fig. 1a. The content of Si phase is decreasing , which in turn means that content of dissolved Si is increased compared to results discussed above. Structure of $Al_{70}Co_{10}Si_{20}$(4) shows amorphous plateau around 50-90 deg 2 Theta and minor maxima assigned to crystalline fcc-Al. Similar results were obtained for $Al_{70}Fe_{10}Si_{20}$ (5), where similar behaviour was observed.

Figure 1b.shows the evolution of phase content in Al-Ni-Si system with increasing Ni-content. While addition of 5 at.% Ni (7)is significantly decreasing the content of polycrystalline Si as compared to the binary Al-Si alloy (6) (visible as decreased intensity of the Si diffraction maxima), fcc-Al peaks are still pronounced. Broader diffraction maxima suggest the existence of a certain amount of amorphous (or disordered) phase. Addition of 10 at.% Ni (8) is sufficient to lead to a nearly completely amorphous structure; bimodal broad plateaubetween 50 and 80 degrees 2 Theta can be a signature of either ultrafine nanocrystalline grains of Al or of phase separation in amorphous state similar to that observed in bulk metallic glasses [2].

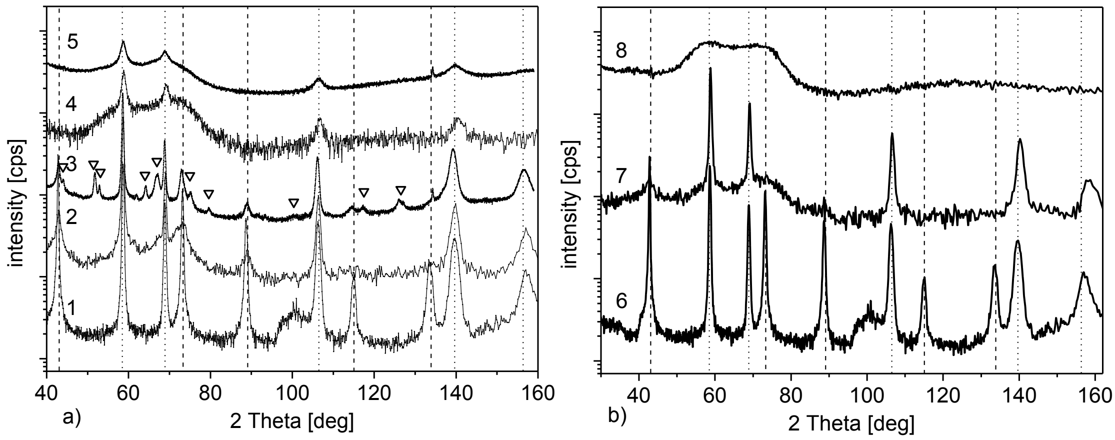

Figure 1: *X-ray diffraction patterns of as-quenched alloys: 1) $Al_{60}Si_{40}$, 2) $Al_{75}Co_5Si_{20}$, 3) $Al_{75}Fe_5Si_{20}$, 4) $Al_{70}Co_{10}Si_{20}$, 5) $Al_{70}Fe_{10}Si_{20}$,6) $Al_{60}Si_{40}$, 7) $Al_{75}Ni_5Si_{20}$, 8) $Al_{70}Ni_{10}Si_{20}$. Dotted lines mark fcc-Al phase peaks, dashed lines mark Si phase peaks. Upside-down triangles mark peaks of complex Al-based phases.*

Alloy thermodynamics and reaction kinetics properties have been examined by measurement of relative electric resistivity during heat treatment. Figure 2.presents measurementsof electrical resistivity R(T)/R(300K) during linear annealing. Steep slope of relative resistivity curves, which means high temperature coefficient of resistivity, of alloys with composition of $Al_{80}Si_{20}$ and $Al_{75}Co_5Si_{20}$ is evidence of polycrystalline structure. Compared to that, alloys with composition of $Al_{75}Ni_5Si_{20}$, $Al_{70}Ni_{10}Si_{20}$ and $Al_{70}Co_{10}Si_{20}$ have much lower temperature coefficient of resistivity, for $Al_{70}Ni_{10}Si_{20}$ and $Al_{70}Co_{10}Si_{20}$even withnegative value. Alloys of $Al_{75}Ni_{5}Si_{20}$, $Al_{70}Ni_{10}Si_{20}$ and $Al_{70}Co_{10}Si_{20}$ were before heat treatment in metastable state and during heating have overcome several phase transformations. Nearly vertical step present in all curves at high temperature end corresponds to melting of Al phase.

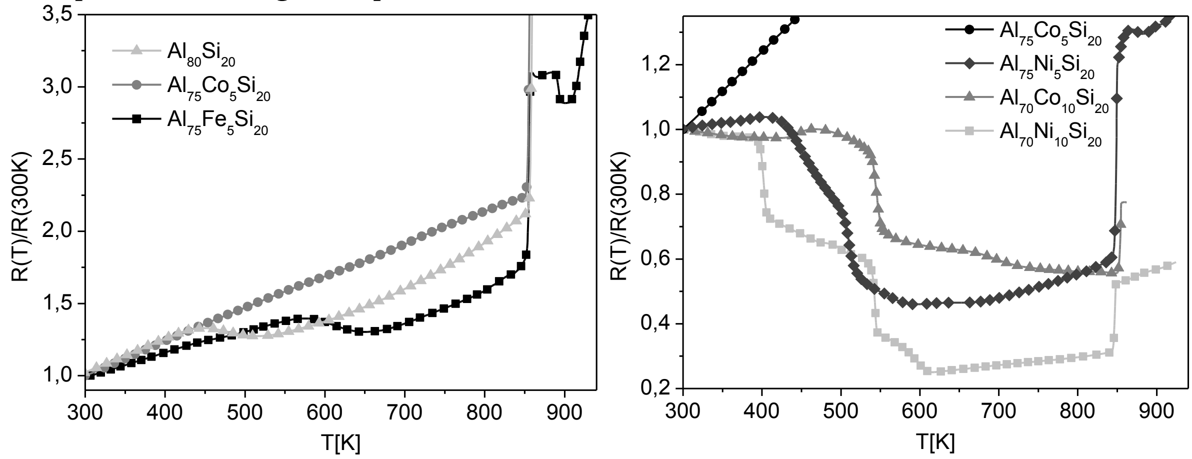

Figure 2: *Temperature dependence of relative electrical resistivity (linear heating 10K/min) for alloys with following composition. Left: $Al_{80}Si_{20}$, $Al_{75}Co_{5}Si_{20}$ and $Al_{75}Fe_{5}Si_{20}$. Right: $Al_{75}Co_{5}Si_{20}$, $Al_{75}Ni_{5}Si_{20}$, $Al_{70}Co_{10}Si_{20}$ and $Al_{70}Ni_{10}Si_{20}$.*

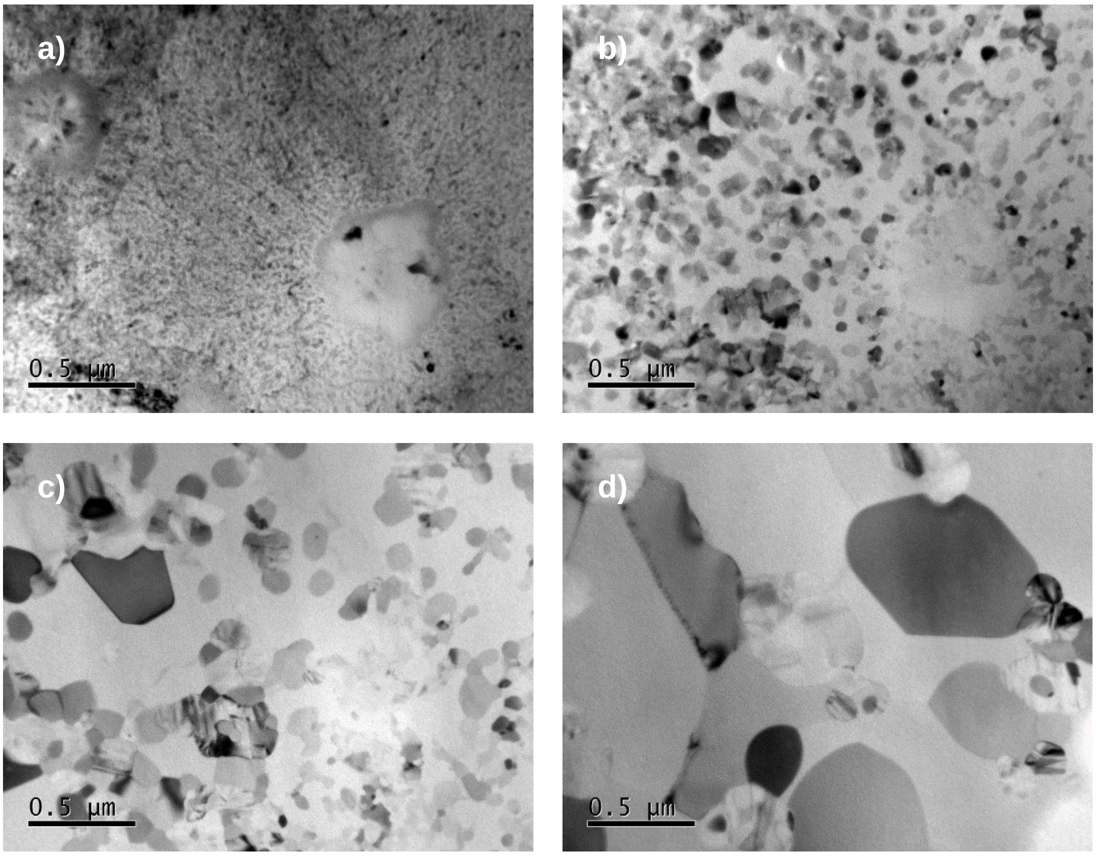

Figure 3: *TEM micrographs of $Al_{75}Ni_{5}Si_{20}$ alloy in as-cast state (a), and during heat treatment at 500K (b), 600K (c) and 800K (d).*

Phase structure of $Al_{75}Ni_{5}Si_{20}$ has been observed by in-situ TEM during heat treatment. Phase composition changes occurred at temperatures corresponding to relative resistivity changes presented in Figure 2. According to measurement of relative resistivity, it was supposed, that as-cast alloy has mixed crystalline and amorphous composition. Figure 3a.shows microstructure of the as-cast state, with amorphous matrix and embedded crystalline structures. During heating to 500K (Figure 3b), growth of fcc-Al(Si,Ni) nanocrystals took place. With further heating to 600K (Fig. 3c) further growth of Al-grains and their coalescence took place. Continued heating between 600 and 800K (Fig. 3d) lead to further coarsening of the fcc-Al phase and to formation of additional intermetallic phases.

4. Conclusions

Rapidly quenched alloys of Al-Si with Fe, Ni or Co have been examined by X-ray diffraction, temperature dependence of relative resistivity and in-situ TEM observations. In the as-cast state, alloys with 5 at.% of transition element were composed mainly of amorphous matrix with embedded fine crystalline fcc-Al and Si phases. For $Al_{75}Fe_5Si_{20}$ alloy, complex Al-based phases were detected. With increasing content of transition element to 10 at.%, structure became more disordered without evidence of crystalline Si phases.

Electrical resistivity measurements revealed metastable nature of $Al_{75}Ni_5Si_{20}$, $Al_{70}Ni_{10}Si_{20}$ and $Al_{70}Co_{10}Si_{20}$. Relative resistivity of $Al_{80}Si_{20}$, $Al_{75}Co_5Si_{20}$ and $Al_{75}Fe_5Si_{20}$ reflected polycrystalline structure. These results are in accord with X-ray diffraction measurements.

In situ TEM measurements of $Al_{75}Ni_5Si_{20}$exhibited mixed amorphous and crystalline structure. Phase growth and transformations were observed during heat treatment, up to 800K.

The border between presence of Si phases and incorporation of Si to other phases was found to be between 5 to 10 at.% of T in $Al_{80-x}T_xSi_{20}$ alloys (T = Fe, Ni, Co). This can help to eliminate Si dendrites in Al-Si based alloys and hopefully enhance mechanical properties.

Acknowledgements

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References

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