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Polarized Light Microscopy – an Essential Method for the Investigation of the Recrystallization of Aluminum Alloys

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The effort to control the microstructure of aluminum alloys in order to obtain specific mechanical properties and performance imposes the necessity to closely monitor and/or predict microstructure transformations during their downstream processing. One of the main features determining the properties of wrought aluminum alloys is the status of their matrix, which may be changed by different thermo-mechanical treatment procedures. The annealing processes of cold and hot worked metals such as recovery, recrystallization (RCR) or grain growth have been the subject of extensive research. A comprehensive guide through annealing phenomena can be found in [1,2]. More recent approaches to the recovery and recrystallization of aluminum alloys are in [3-5]. The present paper will focus on different aspects of recrystallization and the microscopic methods used to study RCR. Examples of the usefulness of light microscopy examinations in the study of RCR of different aluminum alloys will be given.

The progress of recrystallization can be followed by several methods such as calorimetry or measurements of density, electrical resitivity, hardness and proof stress. However, the structural changes expressed in changes of properties are often small and difficult to measure. The most direct and easy method for RCR investigation is by light microscopy examination. In aluminum alloys, Polarized Light Microscopy (PLM) examination of samples, electrolytically anodized in Barker's reagent, gives the best resolution of individual grains. However, the use of this technique is limited to later stages of RCR, because the first nuclei of new grains are often too small to be detected by light microscopy. For early stages of RCR, scanning electron microscopy (SEM - grain contrast regime) and transmission electron microscopy (TEM) examinations are more suitable. Although some particular crystallographic orientations of individual grains can be determined by examinations with polarized light, compete texture evaluation is conventionally done by X-ray diffraction and more recently by SEM-based electron backscatter diffraction (EBSD) [6].

Several aspects of recrystallization and the factors affecting it's kinetics can be studied by PLM: (i) the temperature of RCR start (only to some extent, more precisely by TEM); (ii) the preferred cites for RCR nucleation such as grain boundaries, localized deformation bands, deformation zones at coarse particles; (iii) the extent of RCR described by the volume fraction of material recrystallized X_V; (iv) the temperature of RCR ($X_V = 50\%$); (v) the grain size, shape and their uniformity through sheet thickness or other directions in extrusions and forgings; (vi) the effect of work hardening and its recovery on material ability to recrystalize at given conditions; (vii) the hindering effect of small particles (dispersoids) both on RCR nucleation and grain growth, etc.

Casting and processing conditions have significant effect on the grain structure and formability of Al-Fe-Mn strips prepared by twin-roll continuous (TRC) casting, cold rolling and annealing [7]. Materials with non-uniform as-cast grain structure cannot be processed to yield good quality thin strips and exhibit coarse grained surface layers, which deteriorate strip deep drawing capability.

The annealing response of Al-Fe-Mn and Al-Fe-Si TRC cast strips and the effect of pre-treatment and cold working rate was studied by extensive use of PLM examination of samples processed using different downstream regimes [8]. It was found that intensive cold rolling results in significant in-situ deformation recovery leading to increased resistance to recrystallization. The occurrence of deformation recovery in the heavily cold worked strips was however detected by TEM.

The effect of stable Al-Sc-Zr precipitates on the resistance to recrystallization due to addition of Sc and Zr to Al-Mg alloys was studies also by PLM [9]. It was found that alloys without Sc and Zr are completely recrystallized when annealed for short times at 350°C, whereas the alloy with small additions of Sc and Zr resists RCR even when annealed for hours at temperatures close to the alloy's melting point. The presence of nanosized coherent Al-Sc-Zr precipitates forming during alloy cooling after solidification was detected by TEM. The effect of a homogenization treatment on the resistance of the alloy against recrystallization was evaluated, too.

The evolution of the grain structure in twin-roll cast Al-Mg alloys during homogenization annealing was studied also using light microscopy [10]. This investigation indicated the importance of PLM observations of samples at the early stages of recrystallization. It was realized that when the process starts at surfaces and gradually propagates deeper into the thickness, it is not suitable to follow the progress of RCR only by hardness measurements on strips surface since this method gives a wrong information on the process. The study showed that the TRC Al-Mg alloy response to annealing depends on alloy composition (Mn and Mg content) and is affected by the application of cold rolling prior to annealing. These factors manifest themselves by different RCR extent and grain size in materials annealed under the same conditions. These findings are of great importance and are used in the optimisation of the downstream processing of alloys intended for automotive applications.

The work presented and several other examples (in the final presentation) of the use of polarized light microscopy prove that it is an essential method for quick and precise investigation of recrystallization and it's impact on the properties of aluminum alloys.

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