Microstructure evolution in aluminium 6060 during Incremental ECAP

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Introduction

An AA6060 Al-Mg-Si alloy was used to investigate the microstructure evolution on X, Y and Z planes after processing by Incremental Equal Channel Angular Pressing (IECAP) at room temperature after 1 and 4 passes. The basic microstructural parameters (mean grain size, grain boundary statistics) were evaluated. Noticeable changes in microstructural parameters were acquired by Electron Backscatter Diffraction (EBSD). Grain size was estimated for high angle grain boundaries (HAGBs), which means that grains with boundaries misorientation angle at least 15° were considered. Additionaly, the misorientation angle distribution is presented in order to determine the changes caused with further material deformation.

Tensile test was performed on samples cut from two directions - direction longitudinal (LD) and transverse (TD) to the direction of last pass of IECAP. Mechanical properties such as yield strength, tensile strength, uniform elongation (A_g) and total elongation (A) were evaluated.

Material & Processing

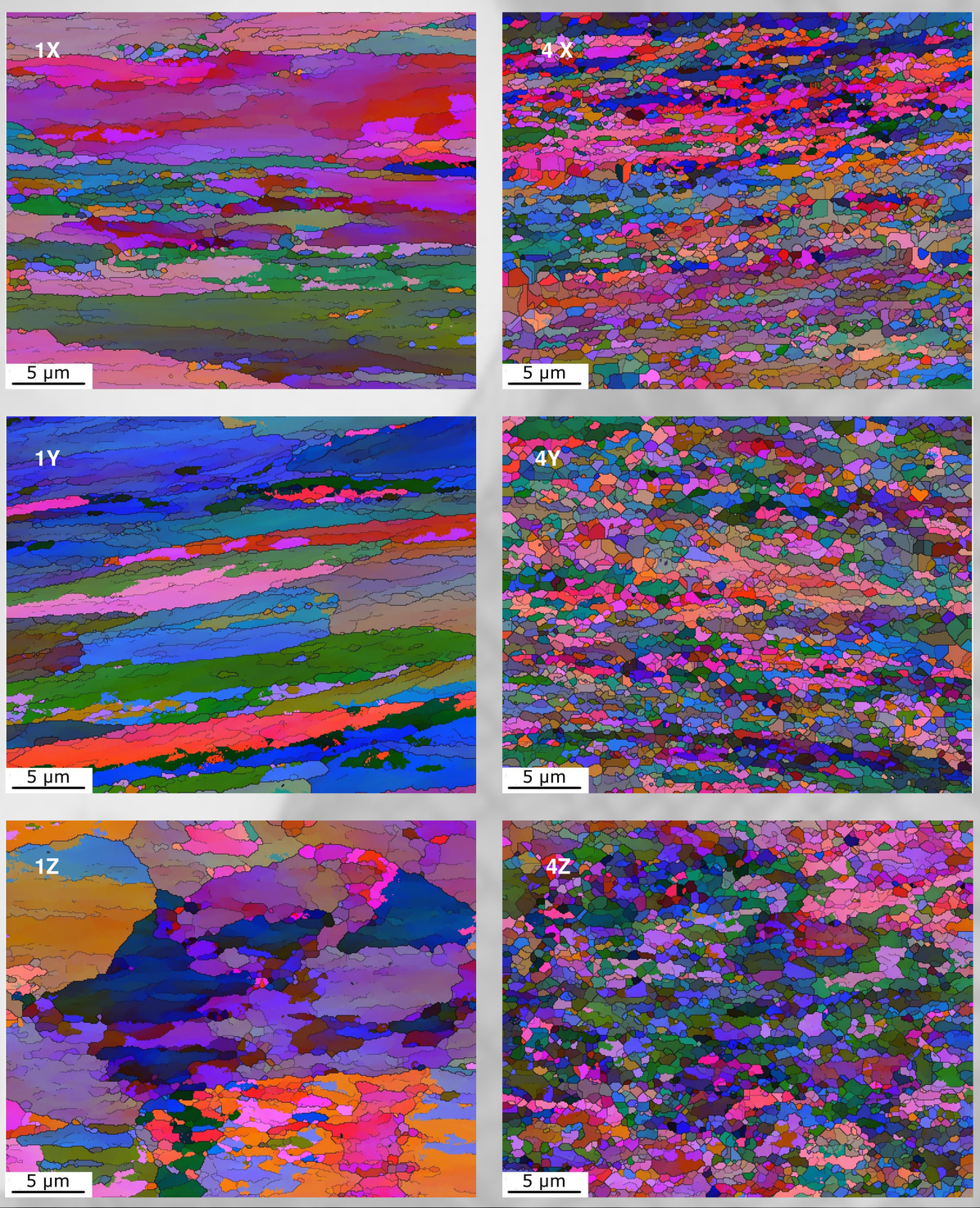
Chemical composition of investigated material AA 6060

Element	Fe	Si	Cu	Zn	Ti	Mn	Mg	Ni	Cr	Pb	Al
Content [wt.%]	0.19	0.43	0.006	0.009	0.005	0.004	0.57	0.004	0.008	0.008	balance

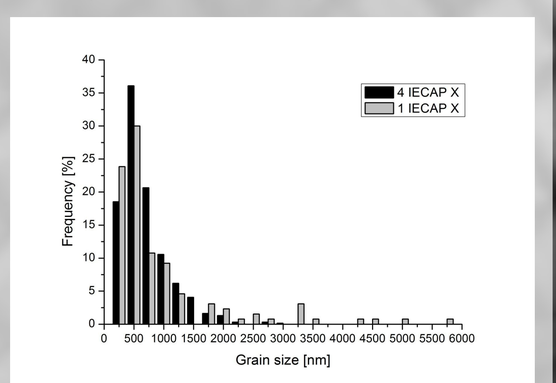
Annealed material was put into Severe Plastic Deformation (SPD) process, named Incremental Equal Channel Angular Pressing. The main idea of IECAP is to apply plastic strain in a series of small deformation increments, which are based on simple shear. As in conventional ECAP, this method has the ability to pass the ingot via different routes. In present experiment, square plates (62 mm x 62 mm x 3 mm) were used, which gave a possibility of employing deformation route based on rotation around the normal to the plate (Z axis). Materials after 1 pass and 4 passes were investigated, which equals of total equivalent strain 1.15 and 4.6, respectively.

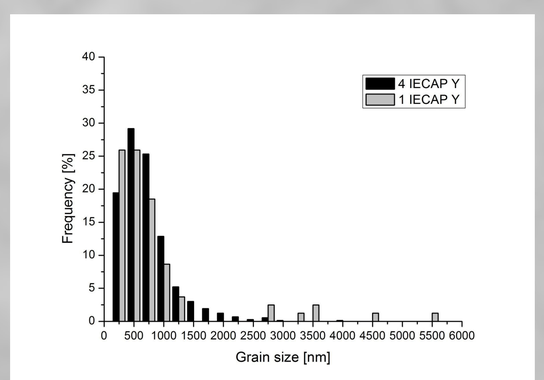
Results

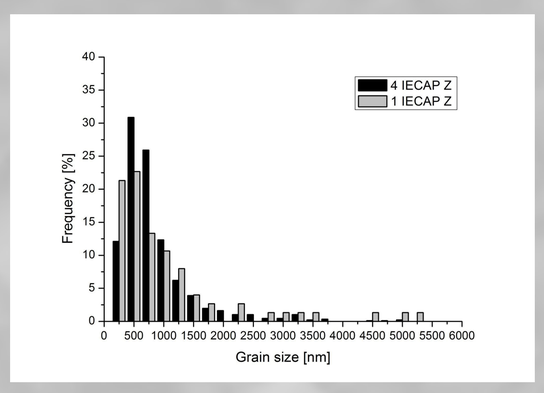
EBSD orientation maps



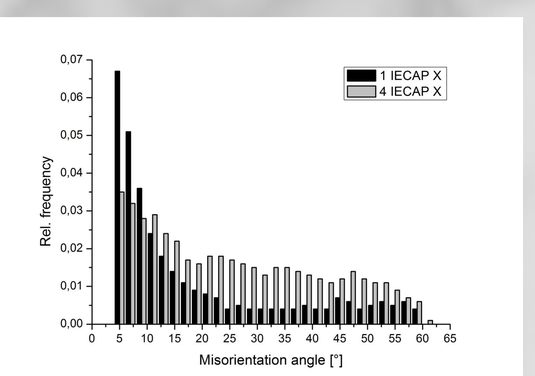
Grain size distribution (>15°) on different planes from EBSD measurements for samples after 1 and 4 passes of IECAP

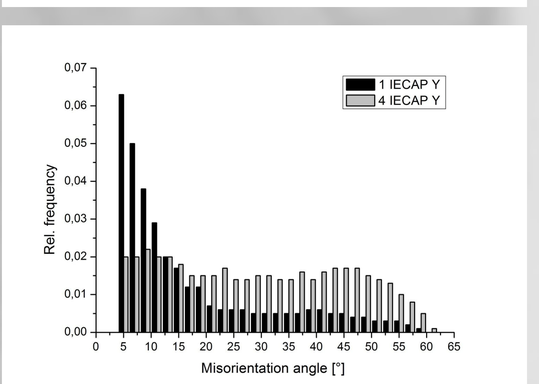


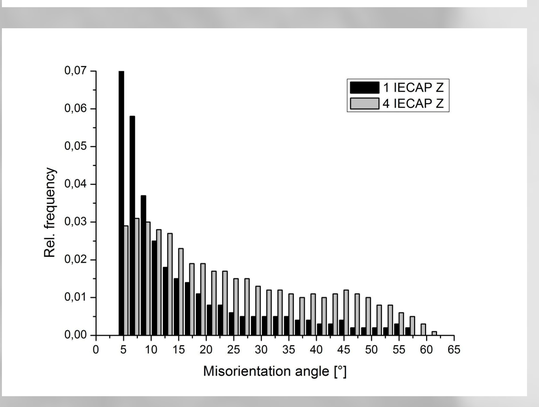




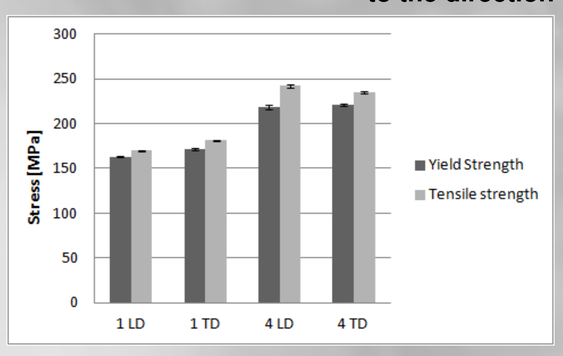
Misorientation angle distribution on different planes from EBSD measurements for samples after 1 and 4 passes of IECAP

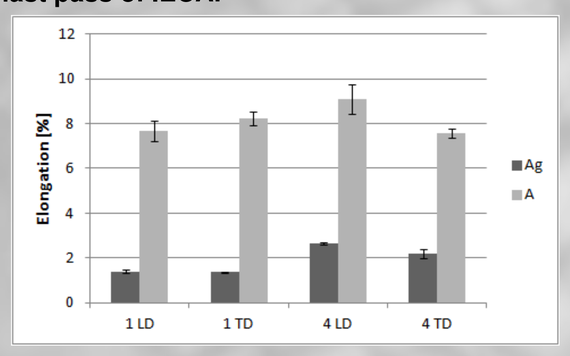






Mechanical properties of samples cut from direction longitudinal (LD) and transverse (TD) to the direction of last pass of IECAP





The summary of quantitative parameters describing AA 6060 microstructures after 1 and 4 passes of IECAP

Parameter	1 X	1 Y	1 Z	4 X	4 Y	4 Z
d [nm]	1453	1717	1573	585	604	729
S.D. [nm]	2693	3595	3364	453	452	637
d_{max}/d	1.78	1.98	1.81	1.57	1.55	1.50
p/d*π	18.01	20.25	20.02	15.31	15.46	15.49

Parameters presented in the Table above:
- d, average grain size, defined as a diameter of circle with the same area as the measured grain,
- S.D. — standard deviation,
- d_{max}/d_2 — grain elongation factor, were d_{max} is the maximum value of grain diameter,
- p/d*π – grain boundary development factor , where p is the grain perimeter.

Apart from distinct grain size reduction, different parameters changed as well. The grain size distribution after 4 passes is less diverse. The shape is more equiaxial, and grain boundaries less developed. Nevertheless, parameters such as standard deviation or shape factors indicate, that the applied strain was not high enough to achieve fully developed high angle grain boundaries.

Conclusions

Incremental Equal Channel Angular Pressing brought a significant grain refinement. Average grain size after 1 pass equals from 1.45 to about 1.72 µm in dependance on the plane. After 4 passes, the average grain size was in the range of 585 to about 730 nm. Together with decreasing the avergae grain size, the diversity of the grain size has been reduced too. Grains became less elongated, with less developed boundaries line. The character of grain boundaries has changed – more HAGBs can be seen after 4 passes of IECAP.

Mechanical properties such as yield strength and tensile strength are increasing with further deformation. Nevertheless, the relative high value of total elongation is preserved after 4 passes of IECAP. The uniform elongation is even higher after larger plastic deformation. It can be caused by the changes in the microstructure and reduced number of free dislocation observed in grain interiors.

Acknowledgements

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