

OPEN ACCESS

Mechanical properties and electrical conductivity of Al 6101 and 6201 alloys processed by hydro-extrusion

To cite this article: Z Pakiela *et al* 2014 *IOP Conf. Ser.: Mater. Sci. Eng.* **63** 012120

View the [article online](#) for updates and enhancements.

You may also like

- [THE UNUSUAL RR LYRAE POPULATION OF NGC 6101](#)
Roger E. Cohen, Ata Sarajedini, Karen Kinemuchi et al.
- [Spectroscopic Study of Four Metal-poor Carbon Stars from the Hamburg/ESO Survey: On Confirming the Low-mass Nature of Their Companions](#)
J. Shejeelammal and Aruna Goswami
- [Probing the Nucleosynthetic Contribution of Low-metallicity, Low-mass Star Companions of CEMP Stars](#)
J. Shejeelammal and Aruna Goswami

ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Mechanical properties and electrical conductivity of Al 6101 and 6201 alloys processed by hydro-extrusion

Z Pakiela¹, K Ludwichowska¹, J Ferenc¹ and M Kulczyk²

¹ Warsaw University of Technology, Faculty of Materials Science and Engineering, Woloska 141, 02-507 Warsaw, Poland

² Institute of High Pressure Physics, Polish Academy of Sciences, Al. Prymasa Tysiaclecia 98, 01-424 Warsaw, Poland

E-mail: kinga.ludwichowska@gmail.com

Abstract. The aim of this work was to produce a material with high strength and electrical conductivity. Two aluminium alloys: Al 6101 and 6201 were used for investigation. Improvement of mechanical properties was obtained by severe plastic deformation, using Hydrostatic Extrusion (HE). To examine mechanical properties of the materials microhardness and tensile tests were carried out. Furthermore, the microstructure analysis was carried out using TEM and light microscopy. Electrical conductivity of materials was measured by 4-wire method. It was found that in the material processed by HE tensile strength and microhardness increased about twice. The biggest strength of 356 MPa was obtained for alloy 6201 after HE. In this case the reduction of a diameters from 20 to 5 mm was used. Examination of the microstructure revealed that as a result of HE grain size refinement to 0.5 micrometer occurred. It was also found that the material has the electric conductivity of about 52% IACS.

1. Introduction

Electrical conductivity is the most important parameter of conducting metallic materials used in electrical engineering. But very often also mechanical properties (yield and tensile strength) are important. Electrical conductivity is very sensitive to the microstructure of the metallic materials, since it is determined by the scattering of electrons because of disturbances in the atomic crystal structure, solute atoms and crystal defects. Solute atoms and crystal structure defects increase mechanical strength of metals, but decrease electrical conductivity. For example pure Al has very high electrical conductivity (62% IACS (International Annealed Copper Standard)), but very low tensile strength. The alloying of pure Al, strain hardening or precipitation strengthening causes increase of its mechanical properties but results also in decrease of its electrical conductivity. The selection of the good materials for power transmission lines is a compromise between their mechanical and electrical properties [1].

The Al–Mg–Si alloys (6xxx series) have been widely used as conductors for overhead power lines owing to their good combination of strength and electrical conductivity compared with other Al alloys. These alloys can exhibit the ultimate tensile strength in the range 255–330 MPa and electrical conductivity between 52 and 57 % IACS [1]. These properties are achieved in the Al–Mg–Si wires after a standard manufacturing route consisting of solution treatment, water quenching and cold drawing into wires, followed by artificial ageing.



Additional increases in mechanical properties of Al alloys, without significant decreases in electrical conductivity can be achieved by grain refinement down to submicrometer scale, using severe plastic deformation (SPD) at room temperature [2].

The aim of the presented paper was to check possibility of increasing mechanical strength of Al alloys without significant reduction of electrical conductivity using hydrostatic extrusion (HE), one of Severe Plastic Deformation methods [3]. By this technique relatively long samples, suitable for applications in electrical engineering could be produced, so it is an important practical aspect of investigation mechanical properties and electrical conductivity of Al wires produced by HE .

2. Experimental procedure and results

Two different Al alloys were casted and hot extruded. They correspond to the commercial standard 6101 and 6201 aluminium alloys. The chemical compositions of investigated alloys are presented in Table 1.

Table 1: Chemical composition of the tested alloys

Alloy	%Mg	%Si	%Fe	%Al
6101	0.57	0.42	0.06	Balance
6201	0.87	0.64	0.07	Balance

The microstructure of the delivered alloys (cast and hot extruded) were characterized using light microscopy and their properties after standard thermal treatment were measured to check that they fit the regular standards.

Both alloys were processed using hydrostatic extrusion. The same processing route was used for both alloys. Starting material was annealed for 1h at the temperature 510°C and then water quenched. Supersaturated samples were hydroextruded at room temperature. Cumulative (multi-pass) HE was run in two consecutive passes, with a total true strain 1.39. MPa. The initial diameter of used rods was 20 mm, and the final diameter of the extruded wires was 5 mm. Properties achieved after HE are presented in Table 2.

The microhardness of the both alloys in initial state and after hydrostatic extrusion was measured on cross section of rods . The materials were tested using hardness testing machine Zwick/Roell ZHU 0.2. The studies have been carried out by Vickers method with a load of 1.96 N. Microhardness profiles for four specimens of the initial state alloys and three specimens of the alloy after hydrostatic extrusion were obtained and their average values and standard deviation were calculated.

The electrical conductivity of 6101 and 6201 alloys at RT was measured using 4-wire method. At least about 10 measurements for each of the materials were taken. Measurements were carried out on various lengths of rods and their average values and standard deviation were calculated (Table 2).

The material processed by hydrostatic extrusion was also tested using tensile test of samples having a gauge diameter of 2.5 mm (Fig. 1), i.e. corresponding to a realistic diameter for a

conductor. Samples were cut out from longitudinal section of rods. Tensile tests were performed using QTest/10 MTS machine. The samples were subjected to tension until failure with constant cross- head speed on value of 0.00375 mm/s corresponding to the initial strain rate 10^{-3} s^{-1} . The yield strength, ultimate tensile strength and the elongation to failure are given in Table 2 for both alloys and compared with the initial alloy (as cast + hot extruded). Exemplary stress-strain curves for the samples processed by HE are shown in Fig. 2. As can be seen the curves of various samples for the same material are similar. The main difference consists in scatter of the elongation to failure. As expected, the 6201 alloy is stronger, but also exhibits lower ductility (Tab. 2).

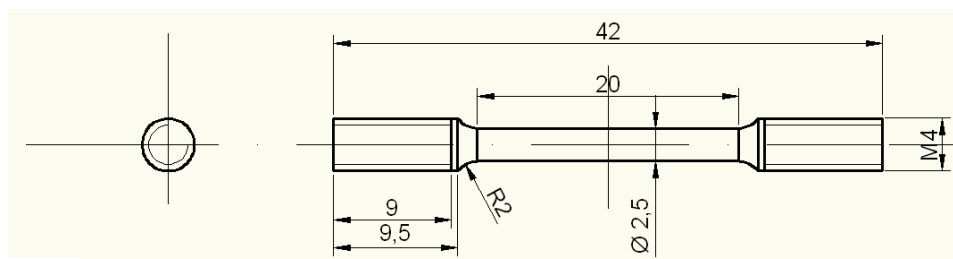


Fig. 1 Dimensions of samples used for tensile tests

Table 2: Mechanical and electrical properties of 6101 and 6201 alloys measured in initial state and after hydrostatic extrusion

Alloy	HV _{0,2}	UTS [MPa]	YS [MPa]	Elongation	Electrical conductivity [% IACS]
6101 Initial	53 +/- 1.6	181	116	0.19	49.9 +/- 0.5
6201 Initial	49 +/- 1.6	163	128	0.19	48.8 +/- 0.5
6101 HE	88 +/- 3	294	280	0.08	52.2 +/- 0.1
6201 HE	101 +/- 2.8	355	336	0.05	48.2 +/- 1.8

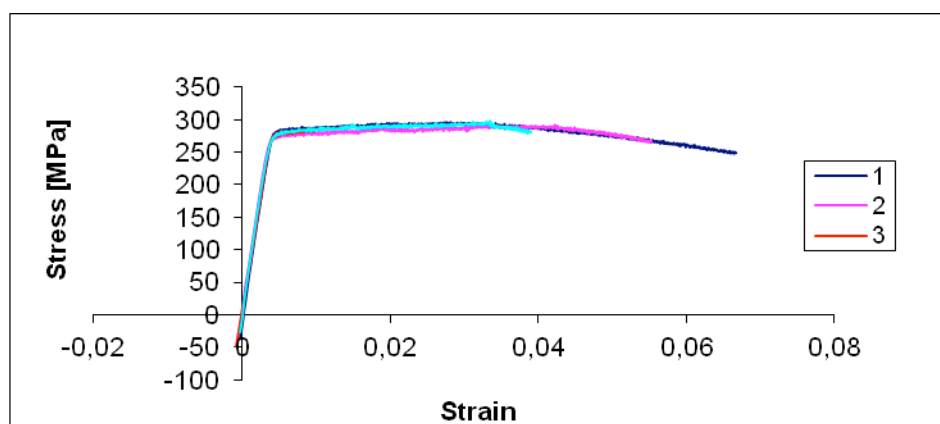


Fig. 2a Tensile curves for 6101 alloy processed by HE

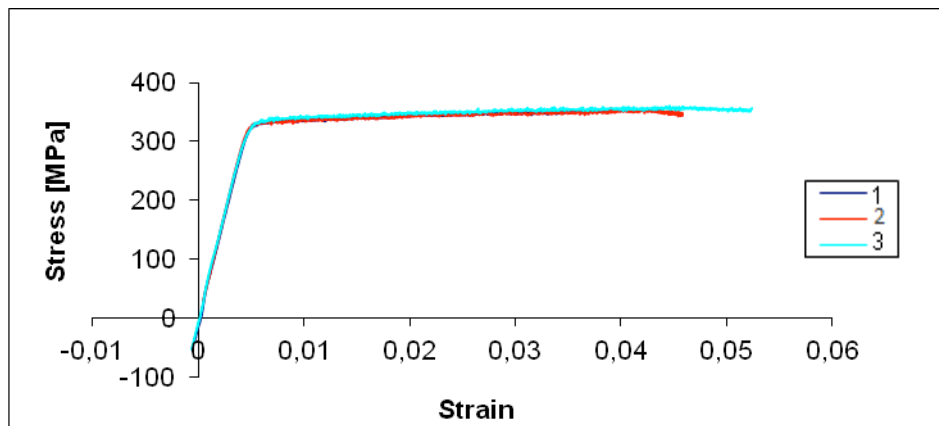


Fig. 2b Tensile curves for 6201 alloy processed by HE

The microstructure of both alloys in initial state was characterised using light microscopy (Fig. 3). To examine the microstructure of the samples surface they were ground, polished to a mirror-like surface and electrochemically etched. Etching was carried out using 0.6% of HBF_4 solution for 90 sec. at an operating voltage of 15 V.

Grain size distributions in both alloys are similar and average grain size was about $120\text{ }\mu\text{m}$. Microstructure observations revealed that there is a significant grain size reduction after plastic deformation by HE of both alloys. Results of grain size analysis for the 6101 and 6201 alloys in initial state and after hydrostatic extrusion are shown in Table 3.

Table 3: Average grain size of the 6101 and 6201 alloys in the initial state and after hydrostatic extrusion.

Alloy	Average grain size [μm]	Standard deviation
6101 Initial	110	60
6201 Initial	129	79
6101 HE	0.44	0.25
6201 HE	0.54	0.31

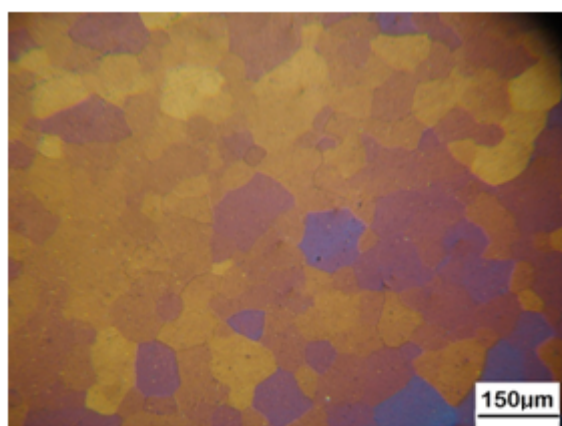


Fig. 3 (a): Microstructure of the 6101 alloy in the initial state

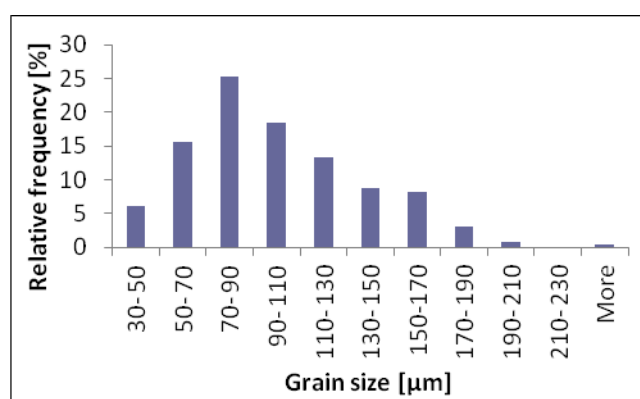


Fig. 3 (b): Grain size distribution measured on (a)

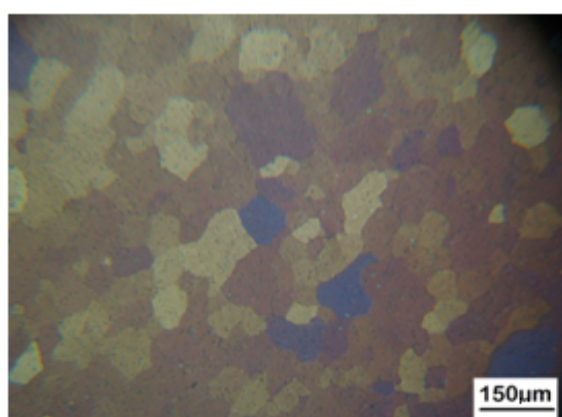


Fig. 3 (c): Microstructure of the 6201 alloy in the initial state

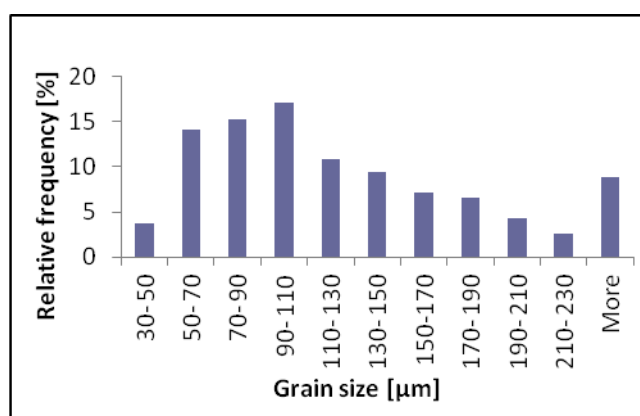


Fig. 3 (d): Grain size distribution measured on (b)

The microstructure of the materials processed by hydroextrusion was characterized by transmission electron microscopy, using a JEOL JEM-1200 microscope operating at 120 kV. Grain size distributions in both alloys are similar and average grain size was about 0.5 μm (Fig. 4).

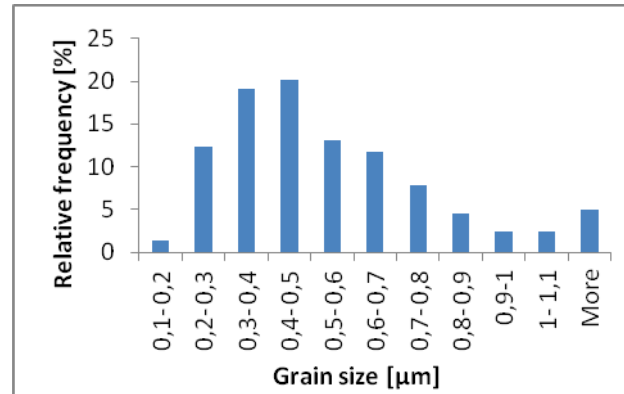
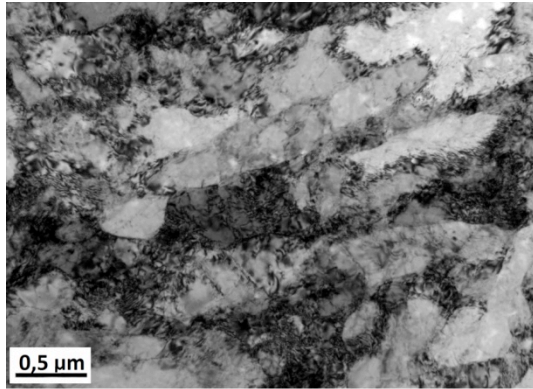


Fig. 4 (a): 6101 alloy processed by hydroextrusion – TEM bright field image showing the fine grained structure

Fig. 4 (b): Grain size distribution measured on (a)

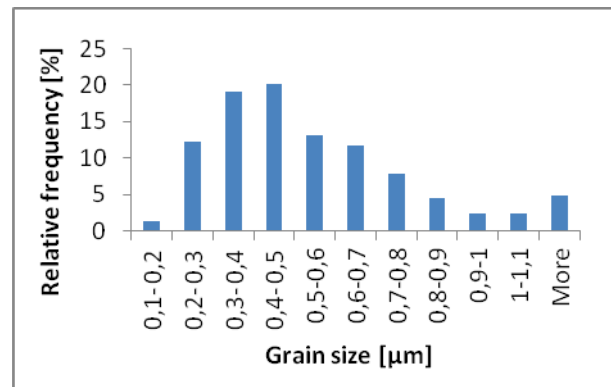
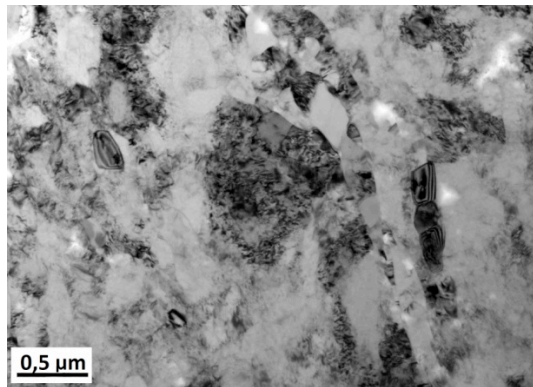


Fig. 4 (c): 6201 alloy processed by hydroextrusion – TEM bright field image showing the fine grained structure

Fig. 4 (d): Grain size distribution measured on (c)

Conclusions

1. Hydrostatic extrusion is an effective way of increasing the strength of the investigated Al-Mg-Si alloys without reducing electrical conductivity.
2. HE is an effective tool for grain refinement in the investigated Al alloys. Examination of the microstructure revealed that as a result of HE grain size refinement to 0.5 micrometer occurred.

Acknowledgements

The authors gratefully acknowledge The National Centre for Research and Development Poland for financial support of this study under ERA-NET RUS initiative (Contract No. NCBR/ERA NET RUS/02/2012)

References

- [1] 2002 *Overhead Power Line Conductors – Bare Conductors of Aluminium Alloy with Magnesium and Silicon Content. European Standard EN 50183*
- [2] Valiev R Z, Murashkin M Yu and Sabirov I 2014 *A nanostructural design to produce high-strength Al alloys with enhanced electrical conductivity Scripta Materialia* **76** pp 13–16.
- [3] Lewandowska M and Kurzydowski K J 2008 *Recent development in grain refinement by hydrostatic extrusion Journal of Materials Science* **23-24** pp 7299-7306.