Archives of Materials Science and Engineering

Volume 39
Issue 2
October 2009
Pages 97-102

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Structure and mechanical properties of AlZnMgCuZr alloy manufactured from powders

J. Senderski [a], B. Płonka [a,*], M. Lech-Grega [a], S. Boczkal [a], W. Pachla [b]

[a] Division of the Light Metals, Institute of Non Ferrous Metals, ul. Piłsudskiego 19, 32-050 Skawina, Poland

[b] Institute of High Pressure Physics of The Polish Academy of Science, ul. Sokołowska 28-37, 01-142 Warszawa, Poland

* Corresponding author: E-mail address: bplonka@imn.skawina.pl

Received 21.07.2009; published in revised form 01.10.2009

ABSTRACT

Purpose: The subject of the research was to study the effect of microstructure and mechanical properties of an alloy AlZnMgCuZr with addition of 0.45 % Zr manufactured from powders. Paper also presents results of different states of precipitation strengthening and further plastic deformation, including hydrostatic extrusion.

Design/methodology/approach: The alloy AlZnMgCuZr was manufactured from powders using hot consolidation in process of direct extrusion and further plastic deformation (hydrostatic extrusion). The microstructure was studied using optical, scanning electron and transmission electron microscopes. The mechanical properties are discussed for different states of precipitation strengthening.

Findings: Obtained results R_m above 700 MPa show significant possibilities of manufacturing Al alloys from powders with ultrafine grain and nanometric structure which properties exceeding alloys manufactured with classical methods.

Research limitations/implications: The further studies are planned with use of plastic consolidation in process of direct extrusion to optimize final process of hydrostatic extrusion. The purpose is to increase mechanical properties.

Practical implications: Extruded products which have higher mechanical properties than the standard are predicted to be used in aircraft industry.

Originality/value: The results of studies and conclusion presented in the paper give prospects for manufacturing products from aluminium alloys offering even better mechanical properties.

Keywords: Al alloys; Powders; Extrusion; Plastic consolidation; Mechanical properties

Reference to this paper should be given in the following way:

J. Senderski, B. Płonka, M. Lech-Grega, S. Boczkal, W. Pachla, Structure and mechanical properties of AlZnMgCuZr alloy manufactured from powders, Archives of Materials Science and Engineering 39/2 (2009) 97-102.

MATERIALS

1. Introduction

The method of hot plastic consolidation, which is an object of the present research and some time ago became a worldwide used technique, consists in integration of materials fabricated by various processes of rapid solidification (atomisation, melt spinning) during hot extrusion process [1,2,3]. In the above described process, the effect of temperature, pressure and deformation results in consolidation of powders and ribbons into

Table 1.
Chemical composition of powder (50-150μm granulation) EN AW-7475 alloy

Alloy	Fe	Si	Cu	Zn	Ti	Mn	Mg	Ni	Cr	Zr
EN AW-7475	0.07	0.03	1.53	5.47	0.008	0.01	2.61	0.07	0.23	0.42

material characterised by density approaching the theoretical value [4,5]. The method of hot plastic consolidation is used in fabrication of materials which, when manufactured by conventional metallurgical methods, are not capable of satisfying the imposed requirements, or cannot be manufactured in any other way [6,7,8].

In this study, the technological investigations have aimed to obtain the possibly highest content of Zr in α solution, which effectively promotes structure refinement and decrease recrystallization at high temperatures, eliminating or reducing the occurrence in structure of coarse precipitates of Al_3Zr phases, harmful to the process of plastic working (reducing alloy plastic properties) [9,10].

2. Materials and methods

The manufacturing process of aluminium alloys from powders by the method of hot plastic consolidation was carried out using EN AW-7475 (chemical composition in Table 1) alloy. The alloy was fabricated by the technique of atomisation, which consists in spraying the liquid metal with inert gas. For investigations some fractions were selected.

The starting product in the form of powder was subjected to hot plastic consolidation. The process of hot plastic consolidation was carried out on a laboratory press of max. 60T capacity, using specially designed and manufactured tools. A set of tools included: ϕ40mm dies for preliminary cold compaction of the stock (Fig. 1), a tool for hot extrusion provided with recipients (containers) of ϕ44mm (Fig. 2), and a set of dies for rods of ϕ12mm and ϕ14 mm (Fig. 3), corresponding to the extrusion ratio of λ=13 and λ=10 [8, 11].

Fig. 1. Die for preliminary cold compaction

Fig. 2. Tool for hot extrusion operating on a vertical press of 60T maximum capacity

Fig. 3. Dies for rods

The established and checked under laboratory conditions, parameters of the hot plastic consolidation process during direct extrusion served as a guideline in designing of equipment and to establish parameters for an industrial-scale research. The industrial trials were carried out on an industrial press of 1250T maximum capacity operating at Grupa "Kęty" S.A. The stock (powder) for extrusion was subjected to preliminary compaction on a 1250T press; the "billets" assigned for hot direct extrusion had the dimensions of ϕ150x300mm (Fig. 4) [12,13,14].

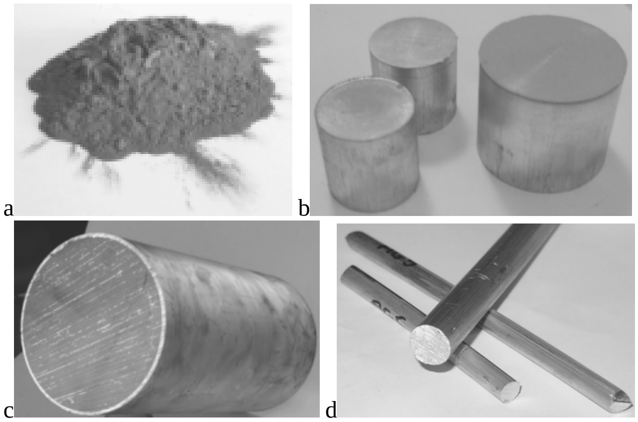

Fig. 4. The stages of hot plastic consolidation (a-powder, b-cold consolidated powder, c-billet of ϕ150x300 mm made from cold consolidated powder for extrusion on industrial press, d-extruded rods)

The next stage of plastic working of this stock was hydrostatic extrusion (Fig. 5). The essence of this process consists in this that a part of the die is filled with liquid which exerts its effect on the processed stock. In this type of extrusion, the stock does not contact the walls of the recipient, due to which the friction forces have values of practically no significance. In this specific case, the values of the extrusion ratio are much higher than in the process of direct extrusion.

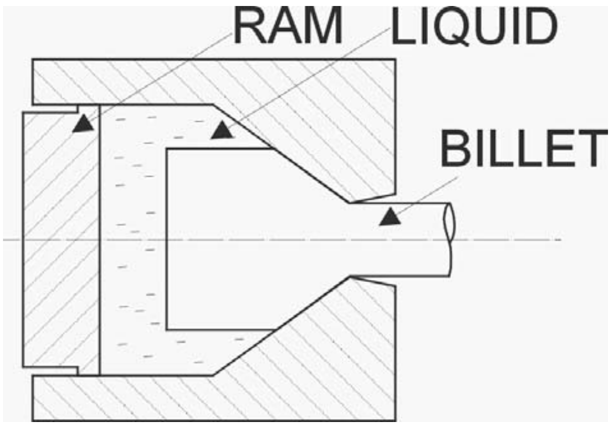

Fig. 5. Schematic representation of hydrostatic extrusion

The obtained stock was subjected to structure examinations and testing of mechanical properties. The structure was examined under the optical light microscope, scanning and transmission electron microscope.

3. The results of investigations

3.1. Microstructure

In microstructures of EN AW-7475 alloy (Fig. 6-8) no precipitates of zirconium were observed or identified by means of analysis of the chemical composition.

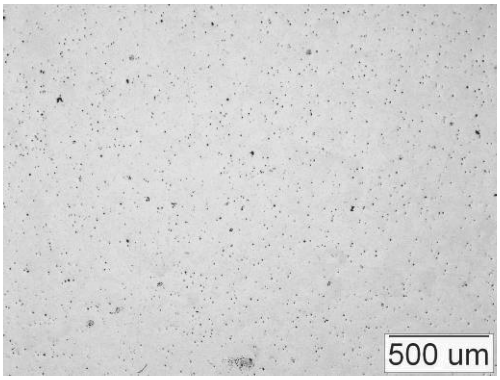

Fig. 6. Microstructure of rods hot extruded from EN AW-7475 alloy powder. Magnification 50x

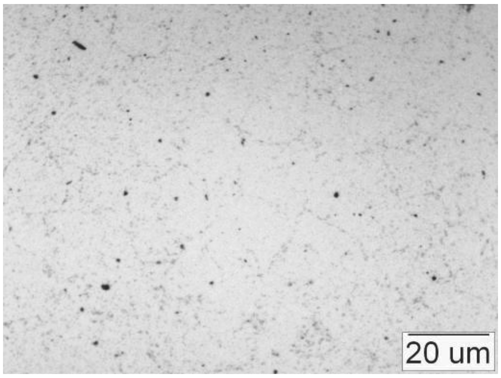

Fig. 7. Microstructure of rods hot extruded from EN AW-7475 alloy powder. Magnification 500x

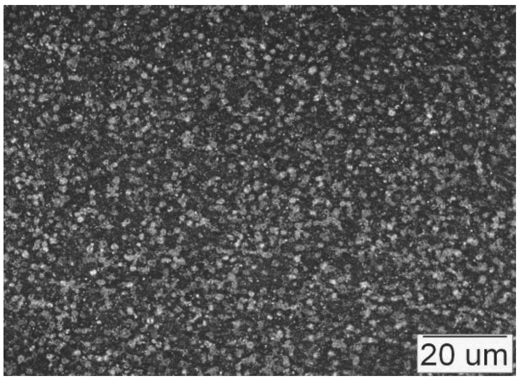

Fig. 8. Grain size of rods hot extruded from EN AW-7475 alloy powder revealed by Barker’s reagent. Magnification 500x

The chemical analyses were carried out in micro areas applying the EDS attachment to the scanning microscope (Figs. 9, 10). They stated that in a matrix are present such elements like Mg, Al, Cr, Fe, Ni, Cu and Zn. The chemical analysis also revealed the presence of zirconium in the alloy matrix (solid solution). Spot analysis (Figs. 11, 12) didn't demonstrate presence of large precipitates of Al_3Zr or different containing Zr (harmful from a point of view of the more further plastic deformation of material and mechanical properties).

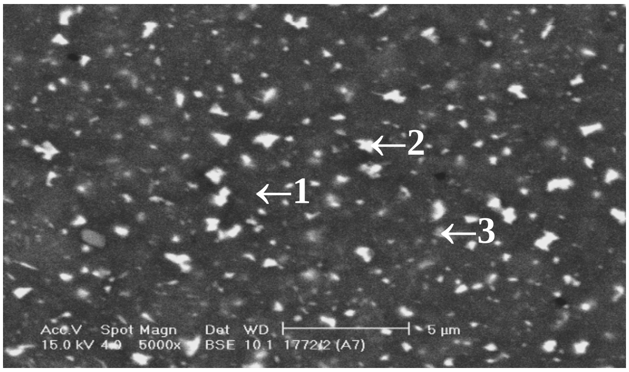

Fig. 9. Microstructure of rods extruded from EN AW-7475 alloy powder (SEM) On this microstructure were marked such places where local chemical analysis was carried out

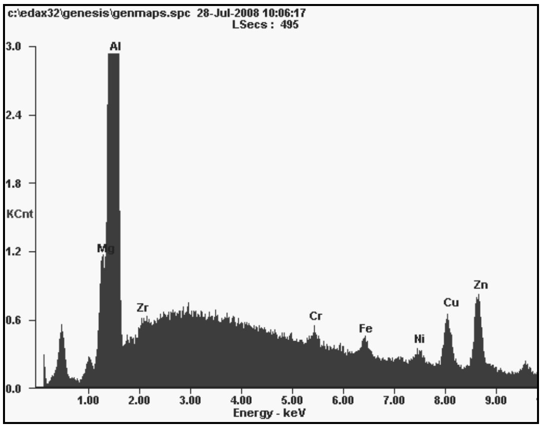

Fig. 10. Local chemical analysis of matrix (point no. 1) alloy EN AW-7475 extruded from powder

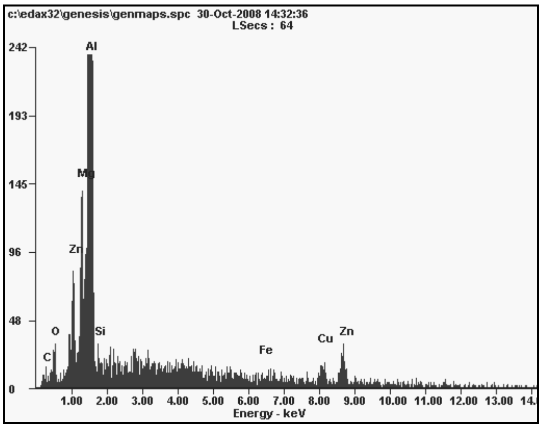

Fig. 11. Local chemical analysis of precipitate (point no. 2) alloy EN AW-7475 extruded from powder

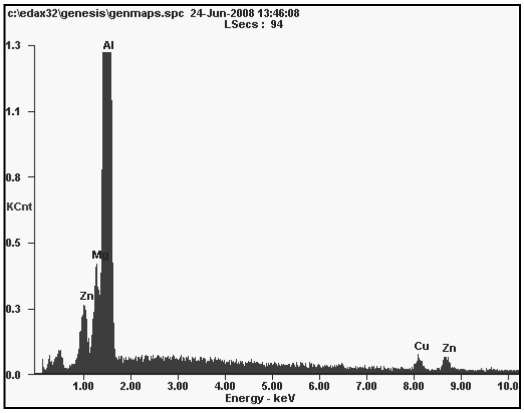

Fig. 12. Local chemical analysis of precipitate (point no. 3) alloy EN AW-7475 extruded from powder

Examination of the microstructure of extruded bars from the powder of alloy EN AW- 7475 was also carried out using a transmission electron microscope. Due to this research, it was possible to find average grain size of 500nm [15]. The electron microstructure (TEM) and histogram of grain size distribution are presented in the Fig. 13.

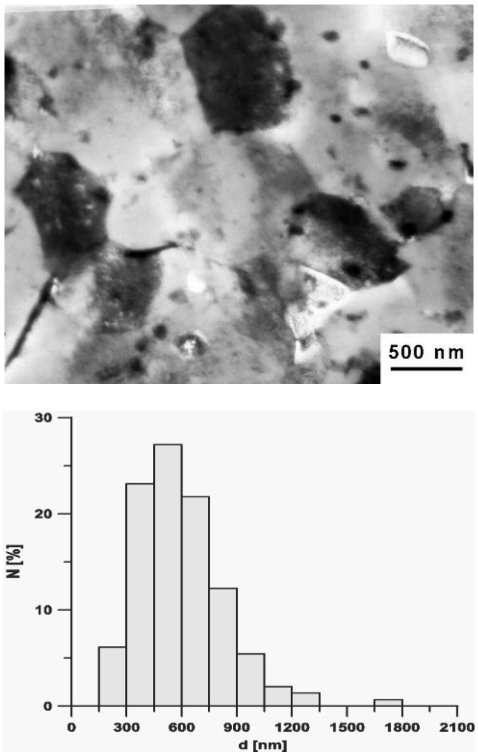

Fig. 13. Example of microstructure (TEM) observed in rods extruded from powdered alloy 7475 and histogram of grain size distribution (average grain size ~500nm)

The initial structure of the examined alloys produced by the hot consolidation of powders is characterised by ultra-fine grains. The size of grains is by two orders of magnitude smaller that it is in the case of alloy fabricated by a conventional process (casting of billets, extrusion).

3.2. Mechanical properties

The extruded rods from the alloy EN AW-7475 with Zr present in the solid solution in an amount of ~0,45% and with the grain size of ~500nm were made. It was possible in of further course of plastic working to subject the rods to a thermal processing (heat treatment and inter-operational annealing) [15]. For this reason an important element of the investigations was assessment of the mechanical properties of rods in as-extruded state and after heat treatment in temper [16]. The mechanical properties determined by the static tensile test are given in Table 2.

Table 2.
Mechanical properties (determined by tensile test) and hardness HB of EN AW-7475 alloy specimens in as-extruded state and after heat treatment

Alloy	Temper*	HB	Mechanical properties		
			$R_{p0,2}$ [MPa]	R_m [MPa]	A_5[%]
EN AW-7475	F	110	332	399	12,6
	T6	173	571	603	11,5
	T73	172	581	601	10,5

* Designation after PN-EN 515 [17]:
- **F**- As-fabricated (untreated) - applies to products shaped in processes without special control over thermal conditions or strain hardening (no limits are guaranteed for the mechanical properties),
- **T6** - Solution heat treated and artificially aged
- **T73** - Solution heat treated and artificially overaged to produce an optimum stress corrosion resistance

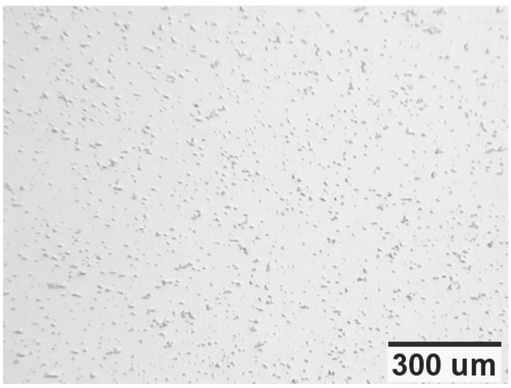

Fig. 14. Microstructure of rods after cold hydrostatic extrusion from EN AW-7475 alloy powder. Magnification 100x

3.3. Hydrostatic extrusion

At the next stage of investigations, the stock after hot plastic consolidation was subjected to cold hydrostatic extrusion. Examples of microstructure and histogram of grain size distribution in materials after hydrostatic extrusion are shown in Figures 14, 15. One can see that average grain size is much smaller after this operation and is equal to 150 nm.

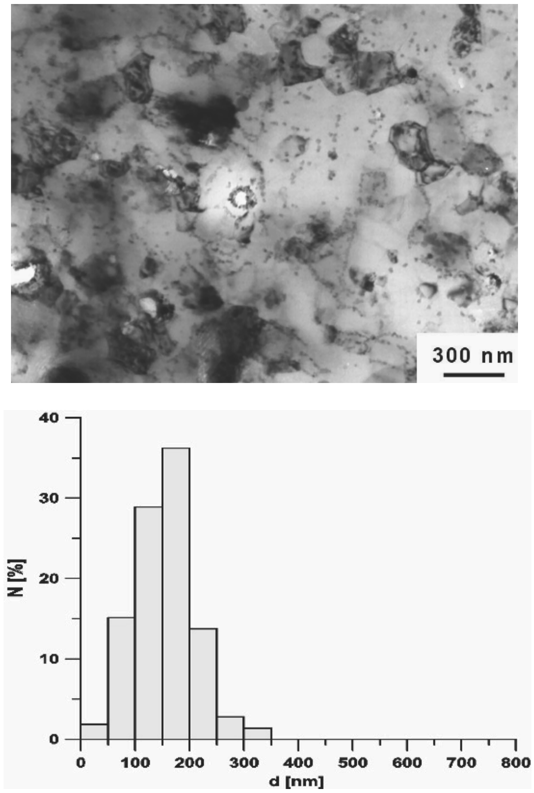

Fig. 15. Example of microstructure (TEM) in rods (cross-section) extruded by hydrostatic technique from EN AW-7475 alloy (average grain size – 160nm) and histogram of grain size distribution

The mechanical properties after cold hydrostatic extrusion in as-extruded state and after heat treatment are given in Table 3.

Table 3.
Mechanical properties (determined by the tensile test) and hardness HB of specimens extruded by hydrostatic technique from EN AW-7475 alloy

Alloy	Temper	HB	Mechanical properties		
			$R_{p0,2}$ [MPa]	R_m [MPa]	A_5[%]
EN AW-7475	F	130	381	460	7
	T6	178	621	670	5
	T9*	---	686	710	2.4

***T9** - Solution heat treated, artificially aged and cold worked (Designation after PN-EN 515:).

4. Summary

The results of examinations of structure evolution in EN AW-7475 alloy fabricated by hot plastic consolidation of powdered stock indicate that materials fabricated by this method are characterised by ultra-fine grain and nanometric structure with mechanical properties exceeding standard level. The developed methods of investigation and planning of experiments, including also the experiments conducted under industrial conditions, allowed to developed effective technologies of fabrication of these materials.

Special attention deserve the solutions applied in industrial technology of making products from AlZnMgCu alloys characterised by the mechanical properties above 700 MPa. This creates the possibility of using these products in aviation and various high-duty constructions. The results of investigations of the technology of making products from aluminium alloys characterised by ultra-fine grain and nanometric structure have proved that it is possible to obtain materials characterised by properties unattainable by the conventional technologies of materials engineering. For an effective application of these products, further development is required to search for a technically and economically viable technology of fabrication.

5. Conclusions

1. The use of EN AW-7475 alloy powder of 50-150μm granulation subjected to hot plastic consolidation enables making of extruded rods of the grain size ~500-600nm.
2. The content of Zr in an amount of ~0,45% considerably increases the alloy resistance to recrystallization and hinders the growth of subgrains at elevated temperatures of deformation.
3. Application of the technology of plastic consolidation tested on EN AW-7475 alloy in the process of direct extrusion and at the next stages of extrusion under hydrostatic conditions enables obtaining higher mechanical properties than the standard of rods in different conditions of precipitation hardening.
4. The results of investigations give prospects to manufacture products from aluminium alloys offering even better mechanical properties.

Acknowledgements

The studies were financed by the State Committee of Scientific Research under Commissioned Research Project PBZ-KBN-096/T08/2003 „Technologie wytwarzania wyrobów z metali i stopów o strukturze nanometrycznej”.

References

[1] M. Galanty, P. Kazanowski, P. Kansuwan, W.Z. Misiołek, Consolidation of metal powders during the extrusion process, Journal of Materials Processing Technology 125-126 (2002) 491-496.

[2] ASM Specialty Handbook, Aluminum and Aluminum Alloys, ASM International, 1993, 649-690.

[3] K. Laue, H. Stenger, Extrusion, American Society for Metals, USA, 1981.

[4] K.T. Kim, J.K. Cho, A densification model for mixed metal powder under cold compaction, International Journal of Mechanical Sciences 43/12 (2001) 2929-2946.

[5] W. Schatt, K.P. Wieters, Powder Metallurgy. Processing and Materials, EPMA, Old Bank Buildings, Bellstone, Shrewsbury, 1997.

[6] C.D. Turner, M.F Ashby, The cold isostatic pressing of composite powders, Experimental investigations using model powders, Acta Materialia 44/11 (1996) 4521-4530.

[7] M. Cholewa, J. Gawroński, Z. Ignaszak, Particles in wear resistance aluminium composites, Proceedings of the 7th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME`98, Gliwice-Zakopane, 1998, 75-80.

[8] J. Senderski, B. Płonka, Deformation Behaviour and Properties of Selected Metallic Materiale, in: chapter VII of the monograph Hot forming of aluminium and its alloys, Silesian University of Technology Publishing House, Gliwice, 2007, 133-161.

[9] K.T. Kim, S.C. Lee, H.S. Ryu, Densification behaviour of aluminum allo powder mixed with zirconia powder inclusion under cold compaction, Materials Science and Engineering A340 (2003) 41-48.

[10] J. Król, J. Senderski, M. Dumańska, M. Lech-Grega, T. Stuczyński, Z. Zamkotowicz, The influence of zirconia addition on the structure of high strength aluminum alloy, Proceedings of the Conference "Aluminium 2000", Krynica, 2000 (in Polish).

[11] S. Karabay, M. Zeren, M. Yilmaz, Investigation extrusion ratio effect on mechanical behaviour of extruded alloy AA-6063, Journal of Materials Processing Technology 135 (2003) 101-108.

[12] J. Senderski, S. Boczkal, H. Dybiec, S. Kivivuory, G. Krallics, M. Lech-Grega, B. Płonka, T. Stuczyński, Plastic Forming of Aluminium Alloys Powders, in: Foundation of Materials Design, Research Signopost, 2006, 321-354.

[13] T. Stuczyński, J. Senderski, B. Płonka, Manufacturing of AlSiNi(Fe) powders and consolidation of semi-products, Proceedings of the International Conference "Aluminium in Transport 2003", Tomaszowice, 2003, 11-25.

[14] J. Senderski, M. Lech-Grega, B. Płonka, S. Boczkal, Structural and mechanical properties in 6101A alloy deformed by ECAE method, Archives of Materials Science 25/4 (2004) 385-390.

[15] D. Vojtech, J. Verner, B. Bartova, K. Saksl, Thermal stability of rapidly solidificated alloys of aluminium with transition metals, Materials Science Forum 519-521 (2006) 389-394.

[16] M.M. Sharma, M.F. Amateau, T.J. Eden, Hardening mechanisms of spray formed Al–Zn–Mg–Cu Alloys with scandium and other elemental additions, Journal of Alloys and Compounds 416 (2006) 135-142.

[17] Polish Standard PN-EN 515, Aluminium and aluminium alloys-Wrought products-Temper designations, PKN, 1996, 14-17 (in Polish).