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The Properties of 7xxx Series Alloys Formed by Alloying Additions

Z. Kwak [a,]*, S. Rzadkosz [a], A. Garbacz-Klempka [a], M. Perek-Nowak [b], W. Krok [c]

[a] Faculty of Foundry Engineering, AGH University of Science and Technology, Reymonta 23 str., 30-059 Kraków, Poland
[b] Faculty of Non-Ferrous Metals, AGH University of Science and Technology, Mickiewicza 30 str., 30-059 Kraków, Poland
[c] Zakład Wlewków, Grupa Kęty S.A. based in Kęty, Kościuszki 111 str., 32-650 Kęty, Poland
*Corresponding author. E-mail address: kwakzosia@gmail.com

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Abstract

Currently there is a constant development in the field of aluminium alloys engineering. This results from, i.a., better understanding of the mechanisms that direct strengthening of these alloys and the role of microalloying. Now it is microalloying in aluminum alloys that is receiving a lot of attention. It affects substantially the macro- and microstructure and kinetics of phase transformation influencing the properties during production and its exploitation. 7xxx series aluminum alloys, based on the Al-Zn-Mg-Cu system, are high-strength alloys, moreover, the presence of Zr and Sr further increases their strength and improves resistance to cracking.
This study aims to present the changes of the properties, depending on the alloy chemical composition and the macro- and microstructure. Therefore, the characteristics in the field of hardness, tensile strength, yield strength and elongation are shown on selected examples. Observations were made on ingot samples obtained by semi-continuous casting, in the homogenized state.
Samples were prepared from aluminum alloys in accordance with PN-EN 573-3: 2013. The advantage of Al-Zn-Mg-Cu alloys are undoubtedly good strength, Light-weight and resistance to corrosion. As widening of the already published studies it is sought to demonstrate the repeatability of the physical parameters in the whole volume of the sample.

Keywords: Variation of the properties, Quality of ingots, Al-Zn-Mg-Cu alloys, Microstructure

1. Introduction

There is a continuous increase in demand for high quality products, with ensured safety of use. Customer demands for the functional properties of aluminum alloys are constantly growing [1]. Accordingly, the aluminum alloys are used as material for pipes, tanks, barrels or heat exchange devices, performing not only their basic function, but also being aesthetic. Aluminum alloys are also used in electrical engineering, as wires, winding in parts of electrical machinery and devices, in the construction sector and in making doors, roofs, car fittings, as well as in the fields of communication and transport, and finally in metallurgy.

The usefulness of aluminum alloys is largely influenced by the possibility of applying appropriate alloying elements and continuous improvement of refining and modification processes. The aluminium alloys have very good properties including fluidity, high tightness and small shrinkage. In the as-cast state, from a practical point of view, aluminum alloys have a plastic and a soft matrix. With respect to composition, the aluminum alloys can be divided into we can distinguish casting alloys and alloys for plastic-processing [2, 3, 4].

Visual aspects of aluminum help to increase its application scope, additionally it is possible to finish its surface by applying a coloured coating or lacquer. The scope of applications is also increased by light weight of aluminum casts. Moreover, aluminum alloys can be used for patterns.

1.1. Classification systems for aluminum alloys for plastic forming

Aluminum alloys are classified on the basis of their main alloying elements. Alloys for plastic-processing and casting alloys have different systems of designation. The symbol of the alloy intended for plastic working is formed based on the PN-EN 573-1 standard, part 1: The numerical designations system. the first of the four digits indicates the alloy group, such as.:

- aluminum 99,00% and more 1xxx (series 1000),
- magnesium 5xxx (series 5000),
- zinc 7xxx (series 7000).

The second digit in an alloy designation shows the modifications in terms of impurities or alloying elements. In the situation, where the second digit is zero, it indicates unalloyed aluminum with a natural, limit value of impurities [5].

1.2. General characteristics of aluminium and its alloys

Aluminum does not have allotropic forms and it crystallizes in regular, face-centred cubic (FCC), with the parameter of 0,40408nm. Aluminium atomic weight is 26,9815, its atomic number equals 13, its melting point is 660, 37^{o}C, and the boiling point is 2494^{o}C. Aluminum density in room temperature is 2,6989g/cm^3. It is characterised by high thermal and electrical conductivity equal to 200W/(mK) and 37,67 Ms/m, respectively. Another characteristic of aluminum is its resistivity to corrosion.

A thin layer of Al_2O_3, appears on its surface and it protects the material against water, atmosphere, concentrated sulfuric acid, several organic acids and hydrosulfuric acid. The progress of aluminum corrosion is caused by reducing acids such as HCl and HF, sea water, steam and mercury ions [6]. Aluminium and its alloys are, however, exposed to corrosion in alkaline solutions, such as NaOH or KOH. Electrolytic process of producing oxide coating (anodizing), aims to improve the corrosion resistance of aluminium and additionally it allows to obtain phenomenal artistic effects.

Technically pure aluminum is not used because of its unsatisfactory mechanical properties and a very large shrinkage. Aluminum alloys designed for plastic working, after solidification, typically consist of soft aluminum grains or a solution of alloyed elements in matrix, while at grain boundaries there are alloying elements, in the form of eutectic or intermetallic compounds which are responsible for the highest hardening effect. During plastic working, grains undergo deformation first, followed by intermetallic compounds. As a consequence, in the aluminum alloys which were plastically formed, a band structure can be observed. It's constitution depends on the type and direction of wrought. The crystals of intermetallic compounds, often crumble into smaller pieces due to plastic forming [7].

1.3. Characteristics of alloys based on Al-Zn-Mg matrix

Aluminum alloys with the addition of a small amount of zinc and other elements are characterized by high mechanical properties. Leaving the ingots after casting, usually up to a few weeks, does not reduce their plasticity, which greatly facilitates their cold-working. The magnesium content in these alloys in the amount of 0.4-0.8% causes their plasticity to be constantly kept at a high level, even after prolonged aging. In addition, these alloys do not exhibit brittleness. Zinc with aluminum forms an eutectic system. Eutectic reaction occurs at the temperature of 655 K (382^{o}C) at 95% zinc concentration. As the result of eutectic reaction, an aluminium solid solution is formed, which contains 82.8% Zn and a solid zinc solution containing 1.1% Al. Zinc strongly affects mechanical and technological properties of aluminum [8, 9].

1.4. Characteristics of 7xxx alloy series

7xxx- series aluminum alloys are casting alloys, which are intended for precipitation hardening. This kind of hardening can only be used for alloys that meet the relevant criteria. The first stage of this process, namely supersaturation, involves heating the alloy to a temperature above the limit of solubility (solvus), keeping the material at this temperature and rapidly cooling. As a result of intensive temperature change, there follows the dissolution of the second phase particles and obtaining the material having the structure of the solid solution α-Al. The second treatment is aging. Which is performed at an elevated temperature, but much lower than solvus or ambient temperature. Aluminium alloys where Zn is the main alloying element, and the additional components are Mg or the Mg and Cu combination, are used particularly in situations requiring high strength material [1, 2]. Aluminum alloys based on the Al-Zn-Mg are characterized by [10]:

- high level of mechanical properties,
- good ductility, formability,
- good machinability and weldability.

2. Research methodology

To assess the ingots quality of the 7xxx series, the following test methods were applied: macro- and microscopic observations using optical microscopy, scanning electron microscopy and chemical composition examination using X-ray fluorescence spectroscopy in microareas. In addition, a study of basic mechanical properties was conducted, namely, hardness, tensile strength, yield strength and elongation.

The study was conducted at the Centre for Research and Development of Grupa Kęty, and at the Faculty of Foundry Engineering at the University of Science and Technology in Kraków.

The ingots were prepared by Direct Chill (DC) casting process. Observations were conducted for the ingots made of EN

AW-7003 and EN AW-7010 alloys, according to PN-EN 573-3: 2014-02.

3. Results

18 samples were prepared from three alloys: 7010K, 7003, and 7003S. The temperature of the beginning, middle and end of the casting process, for all three alloys, was about 678^{o}C. From two randomly selected ingots, coming form consecutive three heats, after homogenization, two slices were cut, 25 mm thick, and additionally two longitudinal slices with a 250 mm thickness. The samples for analysis after longitudinal turning were etched in 20% NaOH water solution to reveal details of the microstructure, then the samples were placed in 20% solution of nitric acid HNO_3 to remove the products of etching.

3.1. Chemical composition analysis

Analysis of chemical composition was performed on transverse sections of samples, using the ARL 3460 OES spectrometer. The chemical composition analysis (fig. 1-3) shows that the content of the elements at the beginning and the end of the ingots is not significantly different. Two groups of ingots made from 7003S 7010K alloy series include in their composition: Zn, Mg, Cu, Fe and Zr, while 7003 alloy does not contain Cu, as a desired alloying additive. Alloy designation of 7003S is a modification of the Grupa Kęty.

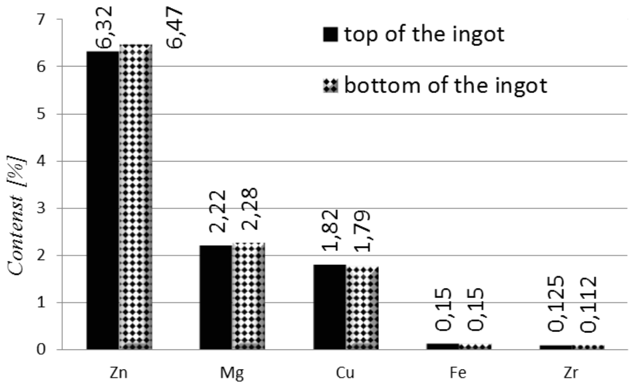


Fig. 1. Comparison of the basic content of alloying elements (Zn, Mg, Cu, Fe, Zr) - 7010K alloy, distinguishing the beginning and the end of the ingot

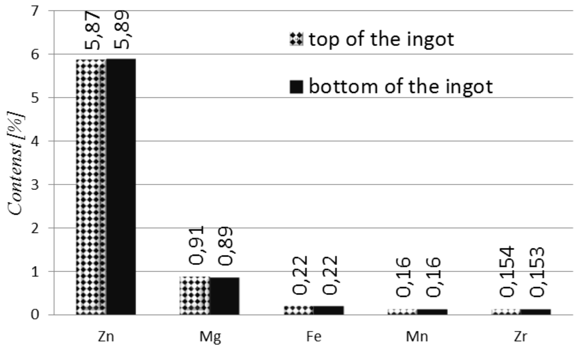


Fig. 2. Comparison of the basic content of alloying elements (Zn, Mg, Fe, Mn, Zr) - 7003 alloy, distinguishing the beginning and the end of the ingot

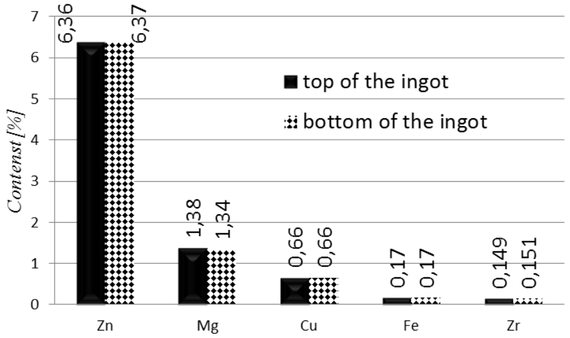


Fig. 3. Comparison of the basic content of alloying elements (Zn, Mg, Cu, Fe, Zr) - 7003S alloy, distinguishing the beginning and the end of the ingot

3.2. Macro- and microscopic observations

The samples for the macro and micro-structural observation were taken from the outer part of the ingots. Surfaces for observation were polished mechanically and electrolytically, and etched. Macrostructure observations for 7010K, 7003, and 7003S alloys (fig. 4-6) were performed on a stereoscopic microscope OLYMPUS SZX10 using Stream motion software.

Additionally, using a Nikon stereoscopic microscope, the microstructural analysis was conducted for a cross-sectional sample of 7003 alloy, (fig. 7-10) using filters.

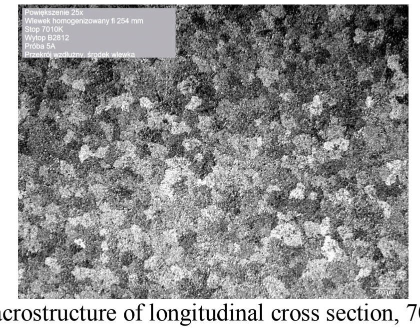


Fig. 4. Macrostructure of longitudinal cross section, 7010K alloy sample - ingot middle section

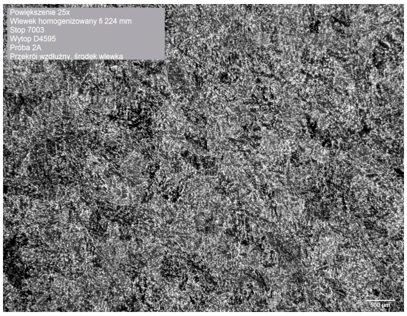


Fig. 5. Macrostructure of longitudinal cross section, 7003 alloy sample - ingot middle section

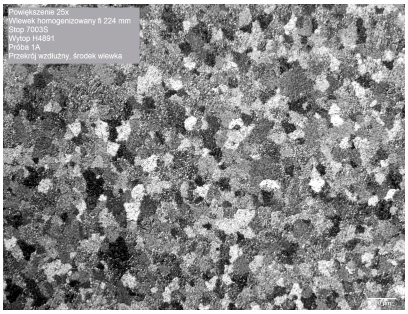


Fig. 6. Macrostructure of longitudinal cross section, 7003S alloy sample - ingot middle section

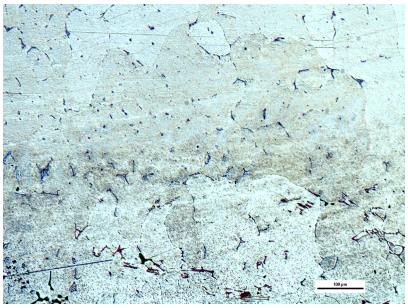


Fig. 7. Microstructure of transverse cross section, 7003 alloy sample - ingot edge section

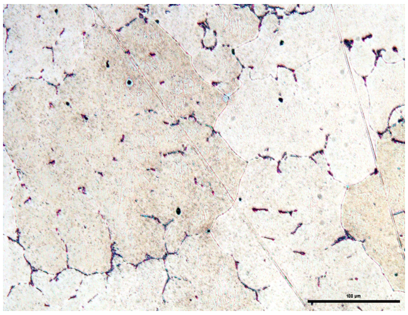


Fig. 8. Microstructure of transverse cross section, 7003 alloy sample - ingot edge section

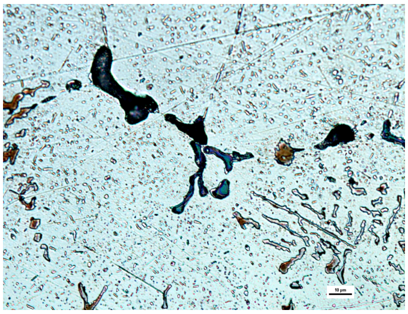


Fig. 9. Microstructure of transverse cross section, 7003 alloy sample - ingot edge section

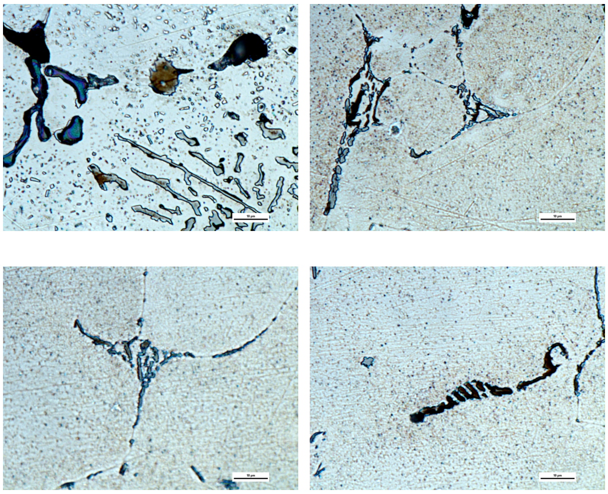


Fig. 10. Microstructures of transverse cross section, 7003 alloy sample

Using a scanning electron microscope (SEM) Hitachi S-3400N with a EDS Thermo microanalysis unit, phase composition observation of the studies material was conducted (fig.11-13), as well as chemical elements present in the microareas were analysed qualitatively and quantitatively (fig.14).

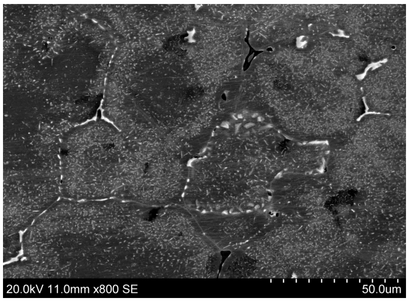


Fig. 11. Microstructure of transverse cross section, 7003S alloy sample, 800x

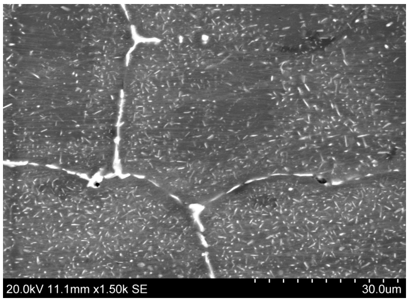


Fig. 12. Microstructure of transverse cross section, 7003S alloy sample, 1500x

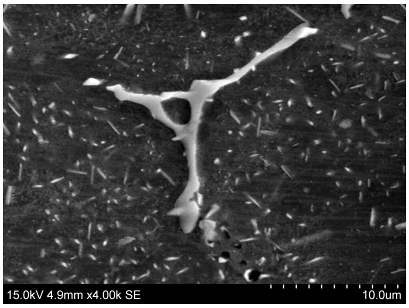
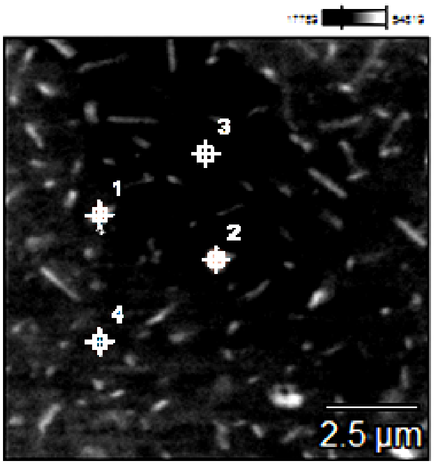


Fig. 13. Microstructure of transverse cross section, 7003S alloy sample, 4000x



Accelerating Voltage: 20.0 kV	Mg	Al	Cu	Zn
7003S (pkt 1)	3.33	79.76	1.00	15.91
7003S (pkt 2)	3.26	80.21	1.27	15.26
7003S (pkt 3)	-	92.61	-	7.39
7003S (pkt 4)	-	91.45	0.85	7.70

Fig. 14. Chemical composition in microareas, 7003S alloy sample, measurement points marked (% weight)

Based on the macrostructure analysis, comparatively the fewest precipitates and with the smallest dimensions can be observed in 7003 alloy. This results from the low supersaturation temperature. Bigger precipitates were observed for the 7003S alloy, and the 7010K alloy was characterised by clear dendritic structure.

In the alloy's microstructure (fig.12) microdendritic segregation is visible, in interdendritic regions, bright, needle-shaped precipitates, containing mainly Al, Zn, Mg are found Cu. At the grain boundaries (fig.12-13) phases rich in Al, Fe, Cu and Zn were identified. Also, intermetallic phases containing mainly Al-Fe (65,5% Al and 23% Fe), with some amount of Zn, Mg and Ni are visible. Moreover, at the grain boundaries there are a few phases containing Si, apart from the elements mentioned above.

3.3. Strength tests

The hardness tests (fig.15) show that the 7003S alloy had the highest HB value (about 99HB), practically within the whole volume of the sample, with the exception of measurement number 7. The 7010K alloy has the lowest hardness (the average value is 80 HB). The hardness for the 7003 sample was about 96 HB.

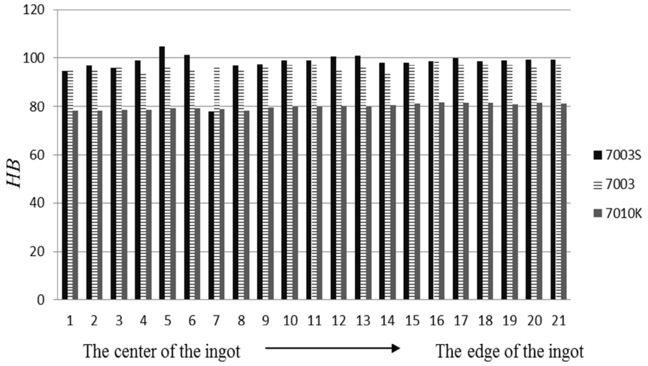


Fig. 15. The HB hardness chart for the 7003S, 7003 and 7010K, the measurements taken from the middle of the sample to the edge

The highest tensile strength was noted for 7003 alloy (fig.16). The highest yield point also belongs to the 7003 alloy (fig.17), lower $R_{p0,2}$ to 7003S alloy, the lowest belongs to 7010K.

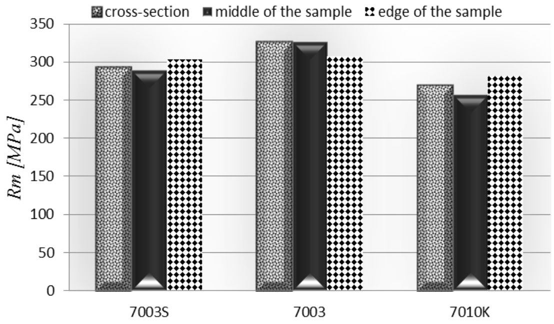


Fig. 16. Tensile strength chart, transverse and longitudinal cross-section, middle and edge of the sample

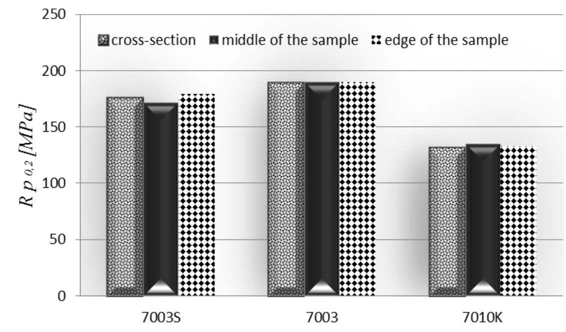


Fig. 17. Yield point chart, transverse and longitudinal cross-section, middle and edge of the sample

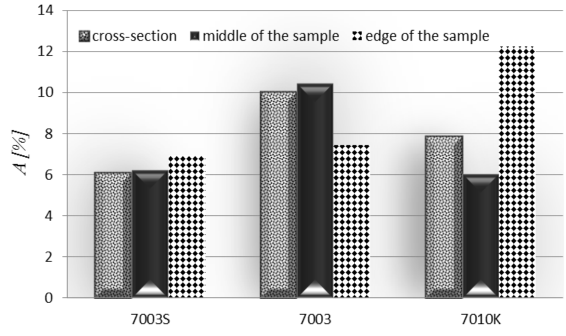


Fig. 18. Elongation chart for the alloys, transverse and longitudinal cross-section, middle and edge of the sample

The 7003S alloy is characterised by the average smallest elongation (fig.18). The elongation values for 7010K alloy in the middle and at the ingot's edge vary considerably. It may be caused by elements segregation.

4. Summary

In the microstructures the boundary region is visible, connected with the microsegregation of infusible components of the alloy. The elements content at the head and foot of the ingots do not vary considerably. The meltings occurring at the bottom part of the ingot are formed due to turbulent flow at the beginning of the casting proces. These imperfections are removed by machining.

The 7010K and 7003S alloys contain Zn, Mg, Cu, Fe and Zr, while the 7003 alloy contains Zn, Mg, Fe, Mn and Zr. The fewest precipitates and their smallest dimensions can be observed in the case of 7003 alloy. This results from the low supersaturation temperature. Bigger precipitates are present in 7003S, while the 7010K alloy is characterised by distinctly dendritic structure.

After supersaturation the alloy's structure becomes more refined, which can be observed in microstructures. The needle-shaped phases in microstructures contain mainly Al, Zn, Mg, Cu. At the grain boundaries, there were identified phases rich in Al, Fe, Cu and Zn. There are also intermetallic phases visible, containing mainly Al-Fe (65,5% Al and 23% Fe), with Zn, Mg and Ni present. Also, at the grain boundaries, a few phases that contain also Si apart from the above-mentioned elements.

The hardness tests show that the 7003S alloy had the highest HB hardness, while the 7010K one, lowest. The highest tensile strength was noted for 7003 and this alloy has also the highest yield point. 7003S alloy has lower proof stress than 7003 alloy, and 7010K - the lowest. The average lowest elongation value characterises the 7003S alloy. The elongation values for the 7010K alloy in the middle and at the edge of the ingot significantly vary. This can be connected with the elements segregation mentioned above.

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