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Comparative Studies of Continuously Cast Semi-finished Al Grade EN AW 1370

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Abstract

The current development of processing technologies of aluminium and its alloys is oriented towards special technologies of continuous casting, dedicated to specific applications. The good point of such approach constitutes limiting of production costs and time needed for making these products. An example of utilising dedicated technologies is sheets production technology of aluminium and its alloys by continuous casting. Another example constitutes technologies of producing charges for the drawing process, where technologies of rods continuous castings of copper and its alloys are known an industrial scale. However, there is a lack of such solutions regarding continuous casting of aluminium and aluminium alloys. Comparative studies of aluminium materials obtained in continuous casting and in continuous casting and rolling technology are presented in the paper.

Keywords: Continuous casting, Aluminium, Aluminium cast, Wire rod, Wire drawing

1. Introduction

Modern metal processing is based on continuous casting processes, which provide semi-finished products in forms of: extrusion ingots, rods for drawing and forging, strips and plates for rolling processes. All these semi-finished products are intended for further processing in plastic working processes. Continuous casting technologies are known already from the year 1856, where Henry Bessemer presented the idea of continuous casting of steel in between two rolls cooled with water. Continuous casting of non-ferrous metals was applied in industry for the first time in years 1930/1940 [1, 2, 3]. Production technologies of charge materials in the non-ferrous metals industry, intended for plastic working are known in the market from more than 50 years. To this end, one of the first solutions was the continuous casting and rolling (CCR) technology of aluminium and its alloys of the Continuous Properzi (CP) Company, developed in 1948. According to the producer’s data, CP lines produce approximately 85% of the world aluminium wire rods and a considerable part of copper, zinc and other metals wire rods [4]. The proper selection of casting line parameters allows to obtain aluminium wire rods of various strengthening states, it means: H11, H12, H13 and H14, which can be later subjected to heat treatments leading to a soft state. Required properties of aluminium wire rods applied for electric aims, are presented in Table 1.

Production of continuously cast materials destined for the drawing process singles out two kinds of technologies. The first kind constitute high yield lines, it means continuous casting and rolling lines (CCR) and the second kind, technologies of lower yields dedicated for specific applications, it means continuous casting lines (CC).

Table 1.
Properties of the aluminium rod

State of the material	UTS, MPa	Elongation, %	Conductivity, % IACS
O	60 ÷ 80	40	63.3
H11	80 ÷ 95	25	61.9
H12	95 ÷ 110	20	61.5
H13	105 ÷ 120	16	61.5
H14	115 ÷ 130	14	61.5

Such lines as: Contirod, Continuus Properzi, Southwire, which are used for production of wire rods of various diameters of such metals as copper, aluminium, zinc, tin and their alloys, can be rated for the group of high-yield technologies. In turn, industrial technologies of continuous casting constitute mainly processing of specific copper alloys (oxygen-free copper) and zinc and they are realized in such Companies as: Vertic, Upcast and Rautomead.

Technologies applied in the aluminium continuous casting are presented in Table 2. It can be seen that the Hazelett, Continuous Properzi and Southwire lines are used for aluminium, zinc, lead and copper [7]. Despite of popularising the continuous casting technology of aluminium and its alloys there is a lack of industrial solutions in the field of producing materials suitable for drawing.

One of the ideas concerning technologies of aluminium processing for wires is based on omitting the hot-strain stage, thus eliminating an additional heat treatment. This method, due to the recovery process of hot-strained aluminium in the CCR lines, avoids the need of wire rod annealing, which significantly decreases production costs. This technology assumes continuous casting of aluminium rods of the needed diameter followed by their direct drawing into wires intended either for stranding or as a charge for other technological processes. The basic advantage of the continuous casting technology (CC) is a lower capital outlay as compared to the CCR system. In addition, it is distinguished by universality in selecting the produced diameters and installation sizes. However, a low yield is a negative side of this technology. The mentioned above factors are the bases to arouse interest - of the production technology of aluminium charges – in small cable plants, which can produce charges for drawing for their own needs [8, 9, 10].

Table 2.
Technologies of continuous casting applied for aluminium [5, 6]

Cast semi-product, product	Technology	Cast material
Sheet, Plate and Foil	Hunter Continuous Casting Process	Al
	Pechiney 3C Process	Al
	Mann Rotary Strip Casting and Rolling Line	Al
	Alusuisse Caster I and Caster II	Al
	Hazelett Twin-Belt Caster	Al, Zn, Pb, Cu, Steel
Rod, Bar and Wire	Properzi Process for Continuously Cast and Rolled Rod	Al, Pb, Zn, Cu
	Cegedur- Pechiney- Secim Continuous Casting and Rolling Process	Al
	Southwire Aluminium SCR Systems	Al, Cu
Ingot, Slab and Billet	Clark Single-Strand Horizontal-Casting System	Al
	Magstaff Horizontal-Casting Machine	Al
	Reynolds Horizontal-Casting Process	Al
	Kaiser Aluminium Process for Horizontal Continuous Casting	Al
	Alcoa Horizontal Continuous-Casting Process	Al

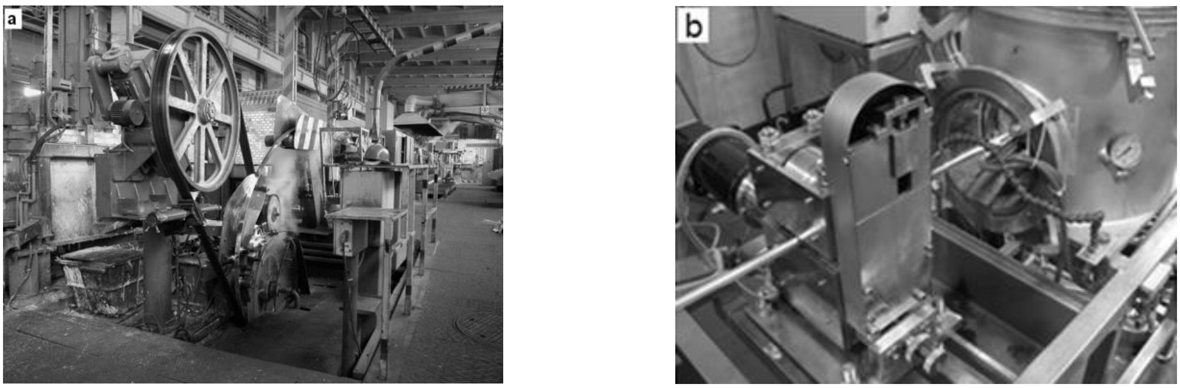

Fig. 1. View of the casting line: a) Continuous Casting and Rolling: Continuous Properzi, b) Laboratory line of continuous casting

The scope of research comprises investigations of mechanical, electrical and structural properties of rods obtained in the continuous casting technology, as well as – for comparison – of the wire rod (of a diameter 9.5 mm) in the annealed state obtained in the traditional CCR technology. In addition, tests of wires of selected diameters produced from the investigated materials in the drawing process, are included in the paper.

2. Investigated material

The aluminium wire rod of the EN AW 1370 grade produced in the CCR line and aluminium rods of the EN AW 1370 grade produced in the CCR line as well as rods obtained in the CC laboratory line [11] were used for investigations. The line is presented in Fig. 1a and 1b, while the chemical composition of the tested materials in Table 3.

Table 3.
Chemical composition of the tested materials

Al	Fe	Si	Cu	Zn
99.82	0.102	0.045	0.003	0.011

The wire rod was annealed to state O, at a temperature of 560°C during heating time: 36 h. Rods of a diameter 14 mm were obtained after melting the charge in the induction furnace and metal heating to a temperature of app. 850°C. The casting process was performed at a drawing rate: 10 mm/s, followed by 5 seconds of a stop. A feed, it means an amount of crystallised metal, which was drawn during the forward movement of the drawing system, was the changeable parameter. Three kinds of feed were applied: the first – 3 mm, the second – 6 mm and the third – 12 mm. During the tests the primary cooling, of water flow 1.5 l/min, and the secondary cooling being 0.4 l/min - was applied. The wire rod and the rod of a feed 6 mm (chosen for testing) were subjected to several tests: macrostructural (Tucker's reagent), electrical conductivity (by means of Sigmatest Foerster), mechanical properties (by means of the testing machine Zwick).

3. Investigation results and their discussion

As the result of the continuous casting of aluminium rods the materials of diversified structure and mechanical properties were obtained. Macrostructures of cast rods in the longitudinal and cross-section are presented in Fig. 2a, b and c.

It can be noticed that materials, after the casting process, are characterised by the typical casting structure, which is composed of grains shaped by the chosen crystallization conditions. The wire rod structure after the heat treatment (Fig. 2d) is characterised by alternately occurring - statically recrystallised during the heat treatment and dynamically recovered during the hot-rolling process - zones.

Physical and mechanical properties of the examined, under laboratory conditions, wire rod materials and the selected rod are listed in Table 4. It can be seen, that the material after the continuous casting has slightly lower strength properties and higher plasticity than the wire rod from the CCR line after the recrystallisation annealing.

Table 4.
Properties of the materials examined under laboratory conditions

Samples	Sample density g/cm^3	Electrical properties		Mechanical properties		
		γ, MS/m	ρ nΩm	YS, MPa	UTS, MPa	A_{100}, %
Cast	2.699	36.6	27.3	18	58	45.0
CCR Rod	2.699	36.8	27.2	23	64	33.5

A further part of laboratory examinations comprised wire rod and aluminium rod drawing processes, which were performed by means of the drawing machine - at the drawing rate of 0.4 m/s - and the set of wire-drawing dies. The drawing process was carried out in such a way as to obtain in both cases the same strain degree equal 93.7 and 99.7 %. Therefore the wire rod CCR was drawn from the diameter of 9.5 mm into the wire of the diameter 2.4 and 0.5 mm, while the rod from the CC line from the diameter of 14 mm into 3.5 and 0.7 mm. Samples, taken from each material after each drawing, were subjected to the uniaxial tensile tests, in order to determine their technological strengthening curves and electrical conductivities. The selected mechanical and electrical properties obtained for the strain degree 93.7 %, true strain 2.76 and the strain degree 99.7 %, true strain 5.81 are given in Table 5.

Table 5.
Electrical and mechanical properties of the wires obtained under the laboratory conditions

CCR Rod – temper O					
True strain	Diameter, mm	ρ, nΩm	YS, MPa	UTS, MPa	$A_{100,}$ %
2.76	2.4	27.8	139	148	1.7
5.81	0.5	27.9	–	203	1.3
Cast					
True strain	Diameter, mm	ρ, nΩm	YS, MPa	UTS, MPa	$A_{100,}$ %
2.76	3.5	27.7	143	145	3.7
5.81	0.7	27.8	–	197	1.5

The technological strengthening curve was constructed during the drawing process in such a way, that after each drawing the samples were taken and then subjected to the uniaxial tensile tests. On the bases of the obtained tensile strength results the curve of the Ultimate Tensile Strength (UTS) as a function of the true strain (logarithmic strain) was constructed. The technological curves of material strengthening after the drawing process are presented in Fig. 3.

For wires of the selected diameter 2.4 and 3.5 mm, corresponding to the true strain 2.76, the softening curves were

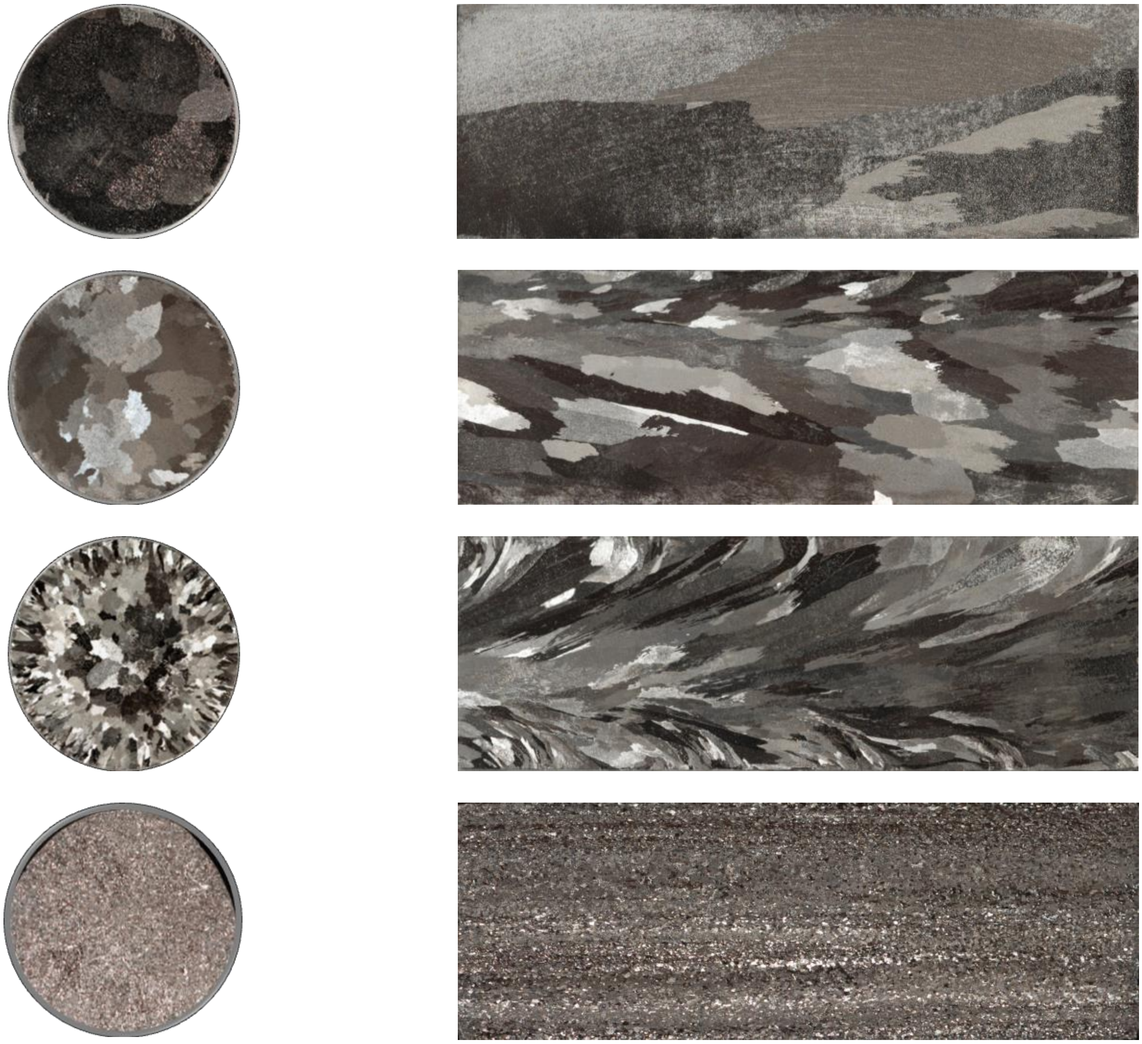

Fig. 2. Macrostructure of cast samples: a) Sample 1 from the CC line - feed 3 mm; b) Sample 2 from the CC line - feed 6 mm; c) Sample 3 from the CC line - feed 12 mm, d) Wire rod from the CCR line in temper O

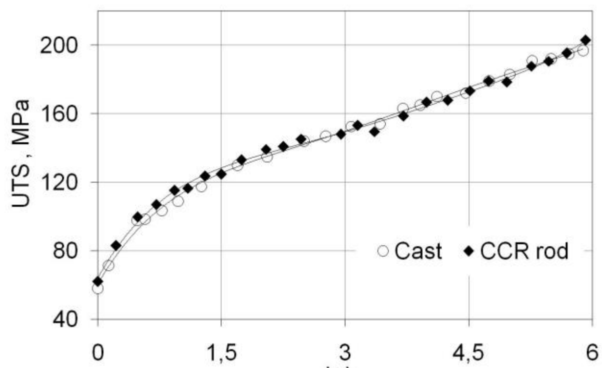

Fig. 3. Technological curves of the strengthening of the tested materials: cast and CCR rod

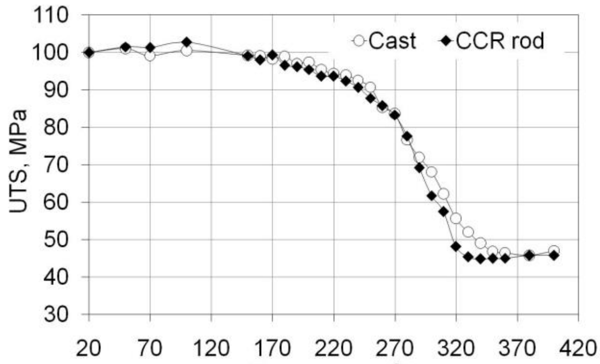

Fig. 4. Softening curves for the tested materials under the laboratory conditions

obtained by means of one-hour heating test in the temperature range: 50 – 400°C. The aim of the test was finding the material recrystallisation temperature. The softening curves of the materials examined under the laboratory conditions are presented in Fig. 4. The recrystallisation temperature of wires of the strain degree 93.7%, true strain 2.76 is higher for the cast equalling approximately 360 – 370°C, while for the annealed wire rod it is on the level: 330 – 340°C.

4. Conclusions

On the grounds of the performed research, which comprised the aluminium (purity 99.7%) casting and processing as well as processing of the wire rod from the CCR line in the annealed state – the following conclusions can be drawn:

1. The continuous casting process provided the material characterised by a uniform structure resulting from the conditions of the casting process.
2. Mechanical and electrical properties of both types of material are at the same level. However plastic properties in case of the cast are higher.
3. Technological strengthening curves in the drawing process are of the same strengthening character, due to which wires of the same strain degree have similar strength and electrical properties.
4. Softening curves of wires of the strain degree of 93.7% exhibit the same character of changes during heating, however in case of wires drawn from materials of the cast structure a slightly higher recrystallisation temperature is noticed.

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