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Twin-roll Casting of High-strength Age-hardened Aluminium Alloys

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By experimental investigations on twin-roll casting of high-strength age-hardened aluminum alloys EN AW-6082 and EN AW-7020 optimal process parameters, which provide a stable and continuous formation of medium thickness strips on the full roll width with a good surface quality, were determined. For the first time the influence of the twin-roll casting and subsequent additional processing on microstructure and mechanical properties of the materials was studied for these alloys. Additional processing included hot rolling and/or heat treatment. It is established that the subsequent treatment of casted bands allows to satisfy the requirements of European standards to the strength and plastic properties regarding high-strength aluminum alloys sheets.

Keywords: TWIN-ROLL CASTING, HIGH-STRENGTH AGE-HARDENED ALUMINUM ALLOYS, HOT ROLLING, HEAT TREATMENT, MECHANICAL PROPERTIES, MICROSTRUCTURE

1. Introduction

Ecological compatibility, quality, power savings – with all of these words it is possible to characterize a trend of development of the metallurgical industry, formed during the last ten-year period. The technology of direct strip production from a melt by means of the twin-roll casting specifies these three requirements. The feature of this strip manufacturing method consists in crystallization and the following deformation of metal in the space between two towards each other rotated rolls, where it`s supplied continuously in the liquid condition. For the first time a description and the basic characteristics, which are necessary for its successful realization have been formulated in 1865 by Sir G. Bessemer [1]. On the **Figure 1** the sketch performed by Sir G. Bessemer is illustrated. This gives a simplified representation about the twin-roll strip casting technology. It is necessary to note that already in this early work such specific elements of the equipment are detailed as water cooled rolls (*a*), lateral seals (in **Figure 1** aren't presented) and the device for a rolls surface clearing (*e-f*) which are present at the modified kind on modern casters. Because of the technical complexity of the twin-roll casting process organization its industrial realization has delayed the idea for almost hundred years and was implemented in 50s of the last century. The technology has been tested for the first time on the pure aluminum by the American firm Hunter Engineering (nowadays FATA Hunter) [2], and also in the USSR by manufacturing roofing sheets from pig-iron [3]. In the last case, however, the plastic deformation of metal in the two-rolls-crystallizer was excluded due to processing conditions. Today the level of metallurgical equipment and technologies evolution, due to first of all improvements of the automation systems and development of new heat resistant materials, has allowed to extend the specified method of thin strip production to carbon, stainless and electrotechnical steels [4, 5 etc.] as well as on wrought magnesium alloys [6, 7].

2. Twin-roll strip casting of aluminum alloys

As it has been mentioned above, historically aluminum became the first material for which the perspective technology had accomplished, successfully realized for the first time in industry and today most widely been used. The continuous twin-roll strip casting process of aluminum evolved over the last 50 years in the direction of width increasing and thickness reduction of sheets that produced directly from the melt. At the moment modern industrial twin-roll casters of the type SuperCasterPlus® of firm FATA Hunter or Jumbo 3CM® of firm Novelis (before the fusion in 2005 – Pechiney) provide manufacturing of sheets of width up to 2300-2350 mm with

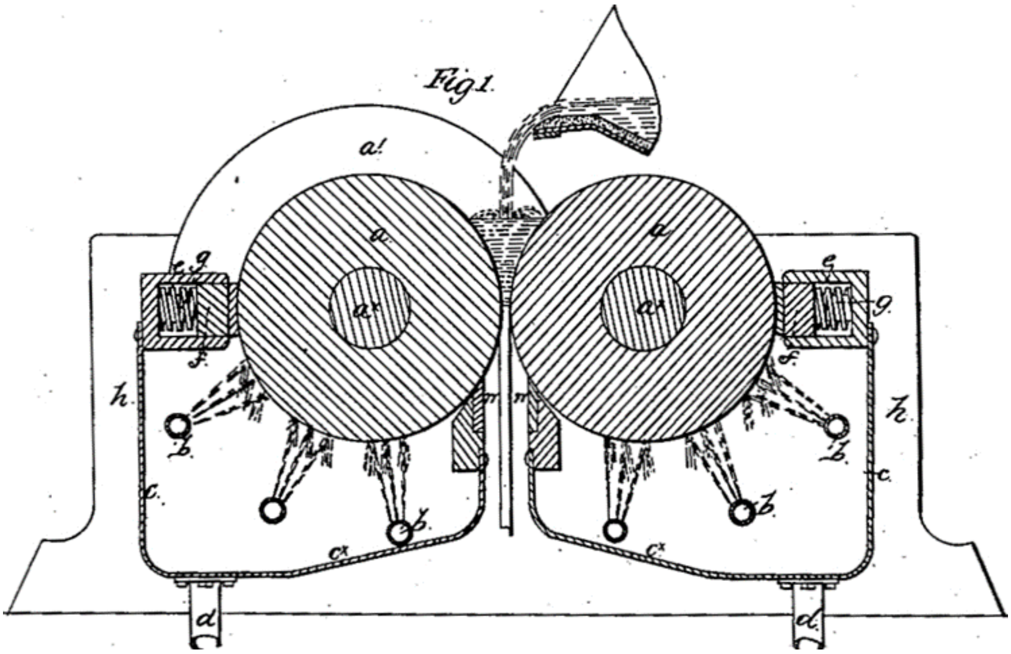


Figure 1. First sketch of a twin-roll caster (1865): *a* – rolls; *a'* – flange; *a** – openings; *b* – pipes; *c* – chambers; *c** – inclined surfaces of the inclosed boxes; *d* – waste-pipes; *e* – grooves/channels; *g* – springs; *f* – blocks of wood; *h* – frame

a minimum thickness of as-cast products of 2,5 mm [8, 9]. Thus, the basic processed material there is pure aluminum used in most cases for the manufacturing of food foils. On the other hand, from the beginning of 80th years the twin-roll casting is successfully implemented to the self-hardening alloys of systems *Al-Mn* (group 3xxx) and *Al-Mg* (group 5xxx). Typical and most widespread representatives of the mentioned binary systems are the alloys 3003 and 5052 [2, 9]. Less often for the thin strip casting the alloys 3105 [10 etc.] and 5182, 5754 [11, 12] are used. The specified aluminum alloys have a wide application spectrum from kitchen utensils to cars and buildings. Besides, in the technical literature there is data about experimental twin-roll casting of bands of age-hardened alloys, such as 6022, 6061 and 6111 [13, 14 etc.] which are related to the medium-strength materials of system *Al-Mg-Si* (series 6xxx). The possibility to increase the strength properties of metal by means of a heat treatment, which in comparison with the annealed condition can reach triple sizes, expands their application on the details of cars and provides a reduction of the structures weight. The specified feature is especially actual for the automobile and aircraft industry because decreasing of fuel consumption and reduction of emissions in the atmosphere of its combustion products. In this context the greatest interest is represented by high-strength age-hardened alloys of systems *Al-Cu* (series 2xxx) and *Al-Zn* (series 7xxx). However the technology of production of strips of the specified materials in the way of twin-roll casting till now isn't developed. That is due to a wide, more than 100 °C, solidification interval of such aluminum alloys. A similar problem is characteristic for the system *Al-Mg-Si* with a high content of alloying elements wise mechanical properties close to high-strength aluminum alloys [2]. Due to the importance of power saving and distribution of non-polluting technologies, activities on the process design and the analysis of the manufacturing conditions influence on the material quality is an actual problem of (the) modern metallurgy. The same concerns the continuous twin-roll strip casting as a potential perspective method for new high-strength materials production.

The aim of the work is an experimental definition of the optimal processing conditions at the twin-roll casting providing stable formation of a strip of the high-strength age-hardened aluminium alloys in a two-rolls-crystallizer as well as to analyze the microstructure evolution, mechanical properties and surface quality of bands by taking into account the possibility of additional hot rolling and various heat treatments of casted metal.

3. Equipment, materials and conditions of investigations

To carry out the experiments a twin-roll casting machine of the Institute of materials science of the Leibniz University of Hanover was used. The two-roll(s)-caster was designed and constructed in scope of scientific cooperation wise the Department of metal forming of the National metallurgical academy of Ukraine. Its purpose is to use the experimental machine for the investigation of forming conditions of strips of alloys on the basis of aluminum, magnesium, and also high-strength steels direct from the melt with a width to 200 mm in a range of thickness of 1 to 5 mm.

Features of the developed twin-roll caster allow to intensify the heat removal from the compound rolls to a liquid cooling medium due to cooling of the internal surface of the sleeves. It allows processing with a high plastic deformation, and changing of the machine tilt angle in a range from 0° to 90°. It is necessary to note that other known laboratory casters with two-roll(s)-crystallizer don't possess a similar combination of the equipment properties. Since March 2010, when the machine exploitation started on technically pure aluminum, a study of parameter optimization on twin-roll casting of strips by thickness from 1 to 5 mm of pure aluminium was carried out. The determined combinations of parameters provide a stable aluminium strip formation lengthwise directly from the melt at their feeding in the vertical plane.

The caster features compound cylindrical rolls with on internal water cooling. External rolls` diameter is 370 mm, the length of the roll barrel is 200 mm. Mill drive is supplied by a motor with a nominal power of 4,4 kW. The maximum strip casting speed is 8 m/min. The main work tool of the machine – the roll sleeves – are made of the heat resisting steel X38CrMoV5-3 (1.2367). Other technical data and design features of the laboratory twin-roll caster are described in detail elsewhere [15].

The aluminium alloys EN AW-7020 of the system Al-Zn-Mg and EN AW-6082 of the system Al-Mg-Si were chosen for the experiments. The last material belongs to the 6xxx-series wise at most medium-strength aluminium alloys. However, the EN AW-6082 has the greatest quantity of alloying components and possesses the greatest strength from the *Al-Mg-Si* system materials. That it`s why the alloy can be classified as a high-strength aluminium alloy. Besides *Mg* and *Si*, the EN AW-6082 contains manganese up to 1%. In **Table 1** the chemical compositions of the materials used during experiments are given. Results of a spectral analysis GDOS demonstrate that the content of the alloying elements corresponds to the standard DIN EN 573-3:2007.

Table 1. Chemical composition of investigated alloys EN AW-6082 and EN AW-7020

Alloying elements		Si, %	Fe, %	Cu, %	Mn, %	Mg, %	Cr, %	Zn, %	Others, %	Al, %
6082	Standard	0,7 – 1,3	max. 0,5	max. 0,1	0,4 – 1,0	0,6 – 1,2	max. 0,25	max. 0,2	-	Others
	Analyses	1,12	0,391	0,084	0,51	0,77	0,03	0,068	0,073	96,954
7020	Standard	max. 0,35	max. 0,4	max. 0,2	0,05 – 0,5	1,0 – 1,4	0,1 – 0,35	4,0 – 5,0	-	Others
	Analyses	0,113	0,174	0,0405	0,145	1,19	0,107	4,37	0,1605	93,70

All experiments were carried out at the twin-roll caster with a vertical feeding of the melt into the roll gap (s. **Figure 1**). That corresponds to a tilt angle of the mill to the horizontal plane of 0°. The supply of material into the space between the rolls was performed through a compound ceramic nozzle depicted in **Figure 2** which has several cylindrical channels. Diameter and quantity of the holes were varied according to the speed of the rolls rotation. The nozzle was installed with a displacement from the formed strip axis towards one of the rolls. In a consequence, the material zone bent towards a roll on which melt is fed after exiting from the crystallization-deformation.

Because of high temperatures of the aluminium and a high pressure during plastic metal forming sticking of the material to the sleeves can occur. To prevent metal sticking on the surface of the steel rolls a thin lubricant layer was superimposed before carrying out experiment.

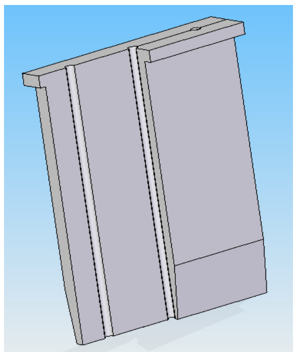


Figure 2. Standard compound of ceramic nozzle with cylindrical channels

Heat removal on an internal surface of both sleeves was provided by a water circulation through the rolls from a high-capacity closed cooling contour. Its liquid temperature is 16 °C, and its flow rate varied in a range from 100 to 112 l/min. This corresponds to conditions of the heat exchange with maximum intensity. Cooling a strip after exiting from the roll gap occurred by free convection.

From above mentioned interval of the possible thickness of the band formed directly in the two-roll-crystallizer of laboratory machine, an average range of the strip thickness and the greatest possible width has been dozen. Thus the flat product thickness exiting from the rolls gap is about 3 mm and its width of 200 mm.

4. Twin-roll casting and subsequent processing of strips of the alloy EN AW-6082

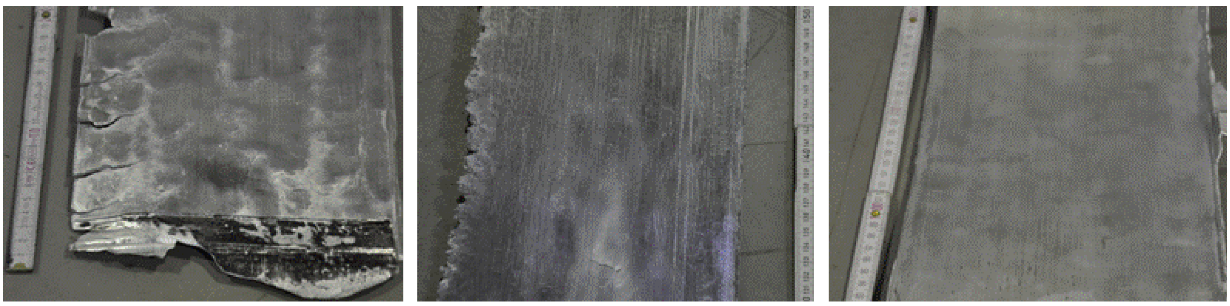
The optimization of conditions of strip formation of 3 mm thickness should be carried out from the point of view of the process stability and obtaining of a strip without casting and surface defects – so-called hot cracks. To define efficient process parameters 19 experiments were carried out which results were analyzed and generalized. The main varied factors, which primary influence on the strip formation at twin-roll casting, are temperature of the melt, speed of casting and height of the crystallization-deformation zone, which was constant during a casting. Diversification intervals of changeable parameters and their values that correspond to an optimal mode of production of medium thickness bands of the age-hardened aluminum alloy EN AW-6082 are given in **Table 2**.

Combination in the right column of **Table 2** of the specified twin-roll casting parameters provides a stable strip formation on all width from beginning to the end of the process. At the same time no leaks of melt from the rolls gap and no high loads on the equipment were registered. Average value of the roll separation force is about 150 kN. Quality of strip surface rises from its forward side, which contains a great number of cracks caused by thermal stresses on the contact between hot melt and initially cold sleeves. After two rolls rotations, corresponding to length of band about 2,4 m, visible defects on a sheet surface are absent. **Figure 3** demonstrates the changing of strip surface quality along its length.

From the flat products manufactured by twin-roll casting samples for a metallographic analysis and for the tensile tests were extracted. The mechanical properties of the age-hardened aluminium alloys in the nontreated state "F" (corresponding to EN 515:1993) without additional processing are not regulated. Therefore, the samples for the tensile tests were hardened at means of a heat treatment on the mode "T6" which consists of a dissolving annealing at temperature 540 °C and duration of 20 minutes, subsequent quenching in water and following artificial aging at a temperature of 160 °C for 8 hours.

Table 2. Choice of efficient parameters for medium thickness strips formation of the aluminum alloy EN AW-6082

Technological parameter	Range of variation	Optimal value
Temperature of the melt, °C	670-710	700
Casting speed, m/min	3,4-3,9	3,5
Height of the crystallization-deformation zone, mm	35-55	45
Nozzle performance	different cylindrical channels	3×∅6,5 mm
Roll surface lubrication	non / graphite / boron nitride	boron nitride
Cooling liquid, l/min	100-112	112



a b c

Figure 3. Strip surface of the alloy EN AW-6082, formed directly from the melt, on its forward side (*a*), on a site corresponding to the second rolls rotation (*b*), on the band end (*c*)

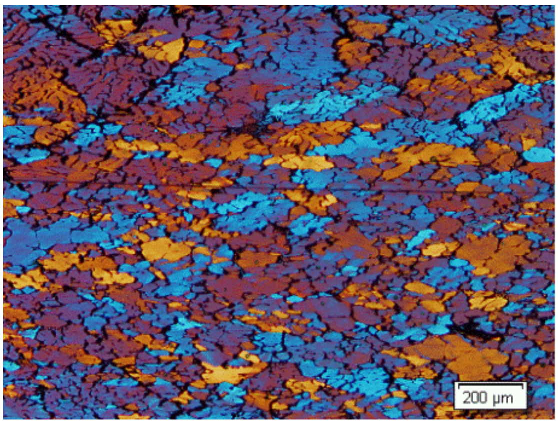
After heat treatment the tensile samples were tested according to standard ISO 6892-1:2009. Results are given in **Table 3**. Each of the values in the given table is averaged from results of three tensile tests.

Results from the **Table 3** show that the strength characteristics of materials after the twin-roll casting and the subsequent heat treatment satisfy requirements of the standard. However, the level of plastic properties of metal is low. Micrographs of the strip in the as-cast state and analysis of the chemical composition of the material allow to explain this effect. A micrograph of the band`s cross-section in the casting direction is depicted in **Figure 4**. It is visible that the grain structure of the metal after twin-roll casting in comparison to microstructures of casted pure aluminum [2] or low-alloyed alloy 6061 of *Al-Mg-Si* system [13] recrystallized much smaller. On the **Figure 4** dendrites can be recognized, which are characteristic for a non- or a weakly deformed state of metal [16]. Such material behavior can be also explained by a respectively high percentage of manganese. That`s slows down the process of aluminium recrystallization and promotes the formation in the sheets made by traditional technology from thin slabs, favorable fine-grained structure [17]. Besides, on the boundaries of some grains segregation zones are observed, which appear in the micrograph of the etched material as long dark areas. It also affects the quality of strips negatively. It is obvious that metal with the characteristics of a cast microstructure can not correspond to the requirements of the standards demanded to thin rolled sheets. Further improvement of the plastic material properties is possible by crushing of dendrites and formations of recrystallized structures. To obtain the desired effect it was decided to process of as-cast aluminium strips with longitudinal hot rolling.

Additional processing was carried out on a laboratory rolling mill "duo" with a roll diameter of 140 mm. Because of limitations on the roll barrel length both edges of the as-cast strips were cut to 15 mm. Hot rolling was carried out at a temperature of 420 °C in four passes on the route 3,0 mm -> 2,1 mm -> 1,65 mm -> 1,35 mm -> 1,0 mm, which corresponds to a total true strain of 1,1 and elongation ratio of 2,9. The first visual impression of the positive influence of the metal forming operation on the quality of strip was an improving of surface appearance. This is explained by the usage of smooth polished rolls. In contrast during twin-roll casting the sleeves surface is weakly profiled. That improves the conditions of initial crystallization of the melt on the rolls. Photos in **Figure 5** illustrate evolution in the appearance of the original cast strip to the finished rolled strip. Also hot rolling processing has a positive influence on the accuracy of the flat product.

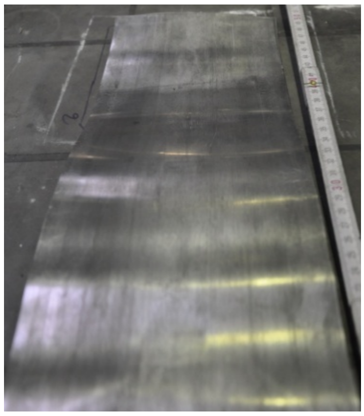
Table 3. Mechanical properties of strip of aluminum alloy EN AW-6082 after twin-roll casting and heat treatment

Charakteristik	In longitudinal direction	In cross-section direction	Requirement DIN EN 485-2:2009
Yield stress , MPa	324	321	> 260
Tensile strength, MPa	348	323	> 310
Breaking elongation, %	2,5	0,3	> 7



Figuure 4. A microstructure of a main line of a cast strip part from alloy EN AW-6082 in a direction of twin-roll casting

a



b

Figure 5. Strip surface of alloy EN AW-6082 in the as-cast cast condition (*a*) and after four hot rolling passes (*b*)

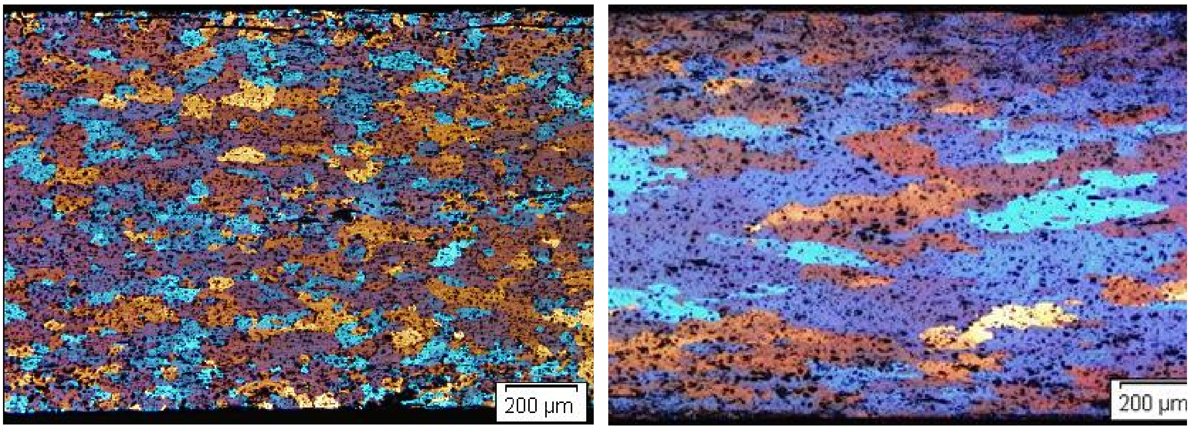
After the plastic deformation of the material a heat treatment consisting of annealing (state "O" corresponding to EN 515:1993 terms) and quenching followed by artificial aging on the regime "T6", which were detailed described above, were accomplished. The annealing was performed at 420 °C for one hour, after which the metal was cooled inside the furnace to room temperature at a cooling rate of 27 °C/h. After two alternative heat treatments of the strip, samples for metallographic analysis and tensile tests in accordance to ISO 6892-1:2009 were prepared. Results of the tensile tests are summarized in **Table 4**.

The data of **Table 4** shows that the additional plastic deformation at high temperature has a positive influence on the ductility of the strips of the aluminum alloy EN AW-6082. The combination of technological operations like a twin-roll casting, hot rolling and a softening or hardening heat treatment allows to achieve a level of mechanical properties according to European standard requirements. Photos of the final material microstructure shown in **Figure 6** demonstrate the structure of recrystallized grains with a large number of intermetallic phases precipitated during the heat treatment. Besides, an intergranular segregation localized near the strip surface is visible. Also, a grain size deviation on the strip thickness draws attention. The later is apparently connected with the as-cast grains size, which in the central part of the in the two-rolls-crystallizer formed band is always greater, than near a sleeves/metal contact zone [2, etc.]. Coarser microstructure of the material after a heat treatment by the mode "T6" compared to the softened metal state can be explained by the influence of the high-temperature annealing. That causes a more intensive growth of aluminum grains.

In order to confirm the improvement of plastic properties of a thin strip obtained by twin-roll casting and subsequent hot rolling and heat treatment three circular samples of a diameter of 75 mm, 85 mm and 95 mm from the prepared sheet material of 1 mm thickness were cut out. At the Institute of Forming Technology and Lightweight Construction of the Technical University of Dortmund deep drawing to “cups” was carried out at room temperature. The punch diameter was 50 mm. The retaining force was 1,5 kN. During the tests none of the details was destroyed. The draw ratio of 1.9 (**Figure 7**) demonstrates processing the initially twin-roll casted strips of the alloy EN AW-6082 by deep drawing after subsequent additional treatment.

Table 4. Mechanical properties of strips of aluminum alloy EN AW-6082 after twin-roll casting, hot rolling and heat treatment

Material condition	Property	In longitudinal direction	In cross-section direction	Requirement DIN EN 486
O	Yield strength, MPa	69	71	< 85
	Tensile strength, MPa	126	131	< 150
	Breaking elongation, %	29,05	24,23	> 14
T6	Yield strength, MPa	264	266	> 260
	Tensile strength, MPa	325	323	> 310
	Breaking elongation, %	11,67	8,71	> 6



a b

Figure 6. Microstructure of strip of alloy EN AW-6082 obtained as a result of the twin-roll casting and further processing in the form of hot rolling as well as softening (*a*) and hardening (*b*) heat treatment

Figure 7. Cup processed by deep drawing of an initially cast strip of the alloy EN AW-6082

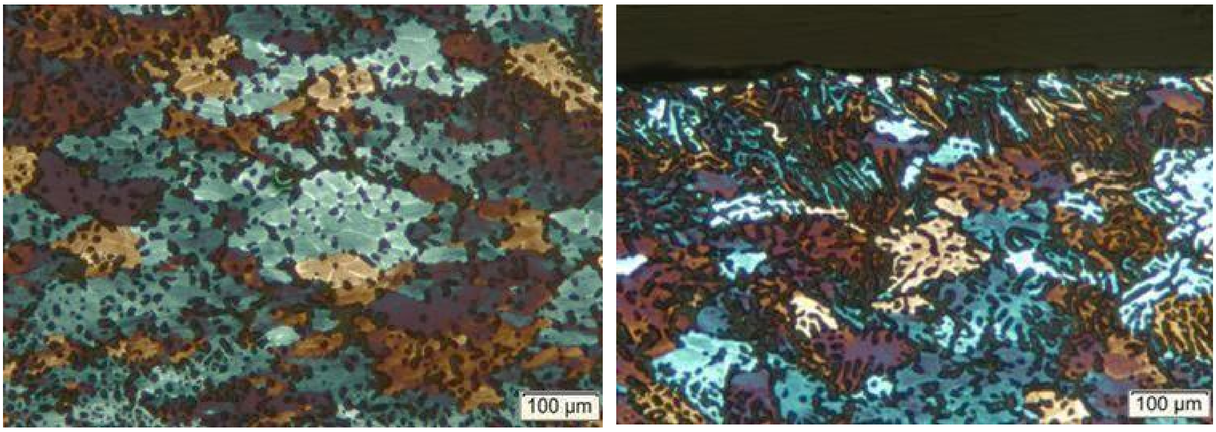
5. Twin-roll casting and subsequent processing of strips of the alloy EN AW-7020

With the aim to define of the optimum mode of the 3 mm strips formation of the high-strength Zn-containing aluminum alloy eight experiments were curried out. The optimization criteria are similar to investigations of the twin-roll casting of the EN AW-6082. Experimental data obtained during the studying of the *Al-Mg-Si* system alloy allowed to perform less experiments for determination of optimum process conditions. The twin-roll casting process parameters are summarized in **Table 5**. Values from the right column of the table correspond to conditions of stable formation a strip direct from the melt along the full roll barrel length from start to finish of casting ensuring a continuous process with moderate loads on the equipment.

The behavior of the alloy EN AW-7020 during its crystallization conforms to results achieved by twin-roll casting of the EN AW-6082. Because of high thermal stresses on the strip surface a great quantity of cracks at the initial twin-roll casting stage was observed. Then, after the process reaches the thermal-steady state, the number of surface defects is decreases. After three rolls rotations, which correspond to a length of the as-cast strip of more than 3,5 m, the surface quality remains constantly high. It should be noted that, compared to the aluminum alloy which was studied previously, the material EN AW-7020 has a greater tendency to hot fracture in a two-rolls-crystallizer. The number of cracks and their length are greater. Some of them expand to the whole metal thickness. To reach a non-defect band formation stage a longer period of is require. The authors associate the observed effect with the presence of low-melting *Zn* phases in the aluminum alloy of *Al-Zn-Mg* system which reduce the plasticity of material at the high temperatures. **Figure 8** shows micrographs of two characteristic regions of the as-cast strip microstructure which is formed by twin-roll casting of high-strength age-hardening aluminum alloy EN AW-7020. Both of micrographs are prepared in the longitudinal band direction.

Table 5. Choice of efficient parameter for the formation of medium thickness strips of the aluminum alloy EN AW-7020

Technological parameter	Range of variation	Optimal value
Temperature of the melt, °C	685 – 710	695
Casting speed, m/min	3,4 – 3,9	3,6
Height of the crystallization-deformation zone, mm	35 – 50	40
Nozzle performance	different cylindrical channels	3×∅6 mm
Roll surface lubrication	graphite/boron nitride	boron nitride
Cooling liquid, l/min	-	112



a b

Figure 8. Microstructure of strip of alloy EN AW-7020, obtained as a result of the twin-roll casting in its central region (*a*) and near the surface (*b*)

Analysis of the material`s microstructure after twin-roll casting shows that in the center of the strip s recrystallized grain structure occurs. This is caused by a localized plastic deformation at high temperatures. Because of the rapid cooling of the metal during contact with the water cooled rolls near the strip surface a characteristic cast structure remains. Also, traces of segregations are observed. Its level is higher than by the processing of the alloy of system *Al-Mg-Si*. This can be explained by a great content of the alloying elements in the EN AW-7020.

To study the influence of a subsequent processing on the microstructure and mechanical properties of medium thickness cast strips, some of these were heat treated. In addition, experiments on hot rolling of cast flat product were performed. After additional plastic deformation of the thin strips these were heat treated in various modes with the aim of material softening or hardening.

Hot longitudinal rolling of metal was carried out on the already mentioned laboratory mill "duo". The temperature of the material before plastic deformation was 480 °C. The rolling was carried out in two passes on the route 3,0 mm -> 1,55 mm -> 0,9 mm. Like in the case of an additional metal forming of as-cast strip of aluminum alloy EN AW-6082 a plastic deformation in the rolling mill had a positive influence on the surface quality and precision of bands of *Al-Zn-Mg* material. Total true deformation in this case was about 1,2.

To reach a state of maximum plasticity "O" annealing of the metal at 420 °C for one hour was accomplished. Then the material was cooled in the furnace to room temperature with a controlled cooling rate of 20 °C/h. Hardening heat treatment was performed in accordance to "T6" mode. The material was heated to a temperature of 480 °C and kept for 20 min on isothermal mode, providing dissolution of intermetallic phases types $Al_xMg_yZn_z$. Then it was quenched in water to room temperature. The additional processing was completed with a two-stage artificial aging: 100 °C for 10 hours and 175 °C for 3 hours. Alternatively, one as-cast strip of a thickness of 3 mm was quenched in a mode analogous to the ones above, followed by natural aging for 12 weeks (state of the material "T4").

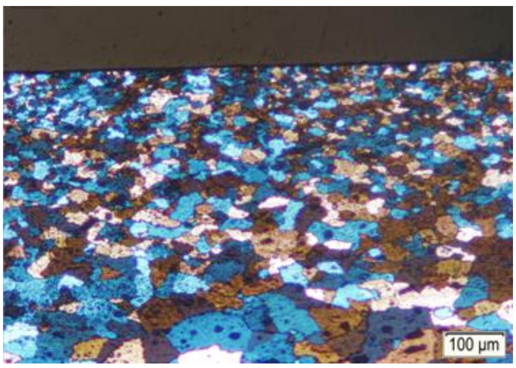
From the unequally processed strips samples for a metallographic analysis and tensile tests in accordance to ISO 6892-1:2009 were prepared. The results of investigations of strength and plastic properties are presented in **Table 6**.

Analysis of data given in the **Table 6** demonstrates that the heat treatment of cast strips of the aluminum alloy EN AW-7020 formed by twin-roll casting provides high plastic metal properties. Elongation of the samples in the states of "O", "T4" and "T6" satisfies the requirements of the European standard. This behavior of material is different from the previously investigated EN AW-6082 due to formation of predominantly recrystallized grain structure in case of EN AW-7020 twin-roll casting (s. **Figure 8**). After the heat treatment at the mode "T6" the strength properties of as-cast strip were not achieved. As result of quenching and natural aging (state "T4") yield strength and tensile strength satisfy the requirements of DIN EN 485-2:2009, but their values were close to the limit.

Hot rolling before the heat treatment improves both the plastic and strength material properties. During plastic deformation at high temperatures a complete recrystallization of the grains occurs (**Figure 9**). An essential grain size deviation along the strip thickness and their orientation in the rolling direction is to be noticed. The grain(s) growth in the strip center is more intensive. Furthermore, a reduction of segregations compared to the as-cast state is visible. That is due to a longer duration of the high-temperature materials treatment during its heating to the hot deformation temperature. This reduction of segregation caused by diffusion of low-melting phases in to aluminum matrix, on the authors' opinion, induces the effect of strength properties increasing by hot formed metal compared to the as-cast material in state "T6". A similar influence may also provided by aprolonged homogenizing annealing. An alternative and more efficient method in terms of energy saving can be a decrease of the casting speed, which reduces segregations in the as-casted strip directly at the operation of twin-roll casting according to B. Forbord [18].

Table 6. Mechanical properties of strips of aluminum alloy EN AW-7020 after twin-roll casting and subsequent processing, including an optional hot rolling and heat treatment

Material condition	Property	In longitudinal direction	In cross-section direction	Requirement DIN EN 486
O	Yield strength, MPa	75	71	< 140
	Tensile strength, MPa	158	159	< 220
	Breaking elongation, %	14,68	13,70	> 13
T4	Yield strength, MPa	215	213	> 210
	Tensile strength, MPa	326	324	> 320
	Breaking elongation, %	14,71	13,06	> 12
T6	Yield strength, MPa	274	266	> 280
	Tensile strength, MPa	325	313	> 350
	Breaking elongation, %	9,91	8,71	> 8
O after rolling	Yield strength, MPa	57	57	< 140
	Tensile strength, MPa	165	163	< 220
	Breaking elongation, %	16,35	13,89	> 12
T6 after rolling	Yield strength, MPa	296	288	> 280
	Tensile strength, MPa	354	357	> 350
	Breaking elongation, %	7,80	7,49	> 7



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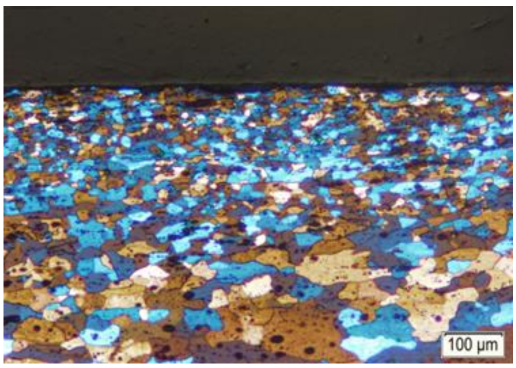

b

Figure 9. Microstructure of a strip with a thickness of 0.9 mm of alloy EN AW-7020 after the twin-roll casting, hot rolling and softening treatment by the mode "O" (*a*) and hardening heat treatment by the mode "T6" (*b*). Microsections are made in the rolling direction

6. Summary

As a result of experimental investigations of twin-roll casting of high-strength age-hardened aluminum alloys EN AW-6082 and EN AW-7020 the optimal process parameters, providing a stable formation of medium thickness strips on the full roll barrel length with good surface quality, are determined. The observed values of the roll separation forces as well as analysis of the material microstructure (indirectly) indicate a high plastic deformation of metal in the two-rolls-crystallizer immediately after solidification. The influence of the twin-roll casting and subsequent additional processing, which includes hot rolling and/or heat treatment, on the quality of the strip surface, microstructure and mechanical properties of the alloys were experimentally defined. It is determined that a hot deformation increases the plastic properties and, for the alloy EN AW-7020 – the strength properties. However, the mechanisms of this influence for metals of the systems *Al-Mg-Si* and *Al-Zn-Mg* are different. It`s shown that the additional processing allow to satisfy the requirements of European standards.

Further investigations may be devoted to characterize the influence of the twin-roll casting conditions on the intergranular segregation at the processing of alloy EN AW-7020 as well as the effect of hot plastic deformation on the recrystallization of the as-cast structure of EN AW-6082. In addition, extending the technology of high-strength age-hardened aluminum alloys strips formed in the two-rolls-crystallizer to the whole possible thicknesses from 1 to 5 mm range is a topical task.

Conclusions

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Валковая разливка-прокатка высокопрочных термоупрочняемых алюминиевых сплавов

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В ходе экспериментальных исследований по валковой разливке-прокатке высокопрочных термоупрочняемых алюминиевых сплавов EN AW-6082 и EN AW-7020 определены оптимальные режимы ведения процесса, обеспечивающие стабильное и непрерывное формирование полос средней толщины на полной длине бочки валка с хорошим качеством поверхности. Впервые для указанных сплавов изучено влияние валковой разливки-прокатки и последующей дополнительной обработки, включающей в себя горячую прокатку и/или термическую обработку, на микроструктуру и механические свойства материала. Установлено, что дополнительная обработка литых полос позволяет удовлетворить требования европейских стандартов, которые предъявляются к прочностным и пластическим свойствам листов из высокопрочного легированного алюминия.