UDK 669.715:620.18:621.74.047
Strokovni članek

ISSN 1580-2949
MTAEC9, 39(4)125(2005)

MICROSTRUCTURE AND FORMABILITY DEVELOPMENT IN Al STRIP CASTING FOR THIN-GAUGE FOIL PRODUCTION

RAZVOJ MIKROSTRUKTURE IN PREOBLIKOVALNOSTI KONTILITIH Al-TRAKOV ZA PROIZVODNJO TANKIH FOLIJ

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Prejem rokopisa – received: 2004-08-16; sprejem za objavo – accepted for publication: 2005-05-23

The changeover to cast Al strip for foil production has been defined by the management of Impol as the key part of its strategy for the plant's development and the restructuring of roll-casting technology.

In comparison with hot-rolled strip, continuous cast strip is a cost-effective raw material for foil production, but different in terms of microstructure, phase composition, formability and other technological characteristics. Due to the very rapid solidification of molten metal in continuous thin strip, the microstructure consists of a strongly supersaturated aluminium solid solution and an increased fraction of fine particles of intermetallic phases, precipitated in Al crystal grains. This has a negative effect on cast-strip formability, and moreover, the cast strip's surface is oxidized and contaminated with graphite.

For the purpose of producing strip from technical aluminium (group AA1xxx) and alloys of the Al-Fe type (group AA8xxx) it was necessary to change the casting parameters as well as the parameters for further strip processing, which differ from conventional roll-casting procedures. Continuous cast strip is primarily intended for insulation, converter and household foils of different widths. The principal foil characteristics, prescribed by EN standards, are the mechanical characteristics, surface quality, porosity and the thermostability.

The research work was focused on achieving the listed characteristics by changing the alloy composition and the conditions of transformation of continuous cast strip into foil. A suitable thermomechanical treatment changes the distribution of alloy elements in the existing microstructural phases and thereby also their effect on static recrystallisation, thereby affecting the surface quality and the mechanical characteristics of the foil.

In this study the optimum composition and the process parameters of continuous casting that make it possible to use the strip as raw material for producing sheets and insulation, converter and household foils of standard quality are presented.

Key words: continuous casting of Al strips, production of foil stock and foils, tailoring of microstructure, composition and formability of strips

Prehod na liti Al-trak za proizvodnjo folij je vodstvo Impol-a opredelilo kot ključni del strategije razvoja tovarne in prestrukturiranja valjarništva.

Liti trak je v primerjavi s toplo valjanim cenejša surovina za proizvodnjo folij, vendar se od njega razlikuje po mikrostrukturi, fazni sestavi, preoblikovalnosti in drugih tehnoloških lastnostih. Zaradi izjemno hitrega strjevanja taline pri kontinuirnem ulivanju tankih trakov prevladuje v mikrostrukturi močno prenasičena trdna raztopina aluminija s povečanim deležem majhnih zrn intermetalnih faz, ki so dispergirano izločene v kristalnih zrnih, kar negativno vpliva na preoblikovalnost litih trakov. Poleg tega je površina litega traku oksidirana in onesnažena z grafitom.

Za izdelavo trakov iz tehničnega aluminija (skupina AA1xxx) in zlitin vrste Al-Fe (skupina AA8xxx) je bilo potrebno opredeliti parametre ulivanja in za nadaljnjo predelavo trakov v primerjavi s konvencionalnimi ulivno-valjarniškimi postopki. Kontinuirno uliti trakovi so prednostno namenjeni za izdelavo izolacijskih, konvertorskih in gospodinjskih folij različnih debelin. Glavne lastnosti folij so predpisane z EN-normami, so mehanske lastnosti, kvaliteta površine, poroznost in termostabilnost. Poudarek raziskovalnega dela v okviru projekta je bil doseganje naštetih lastnosti s spreminjanjem zlitinske sestave in pogojev predelave kontinuirno ulitih trakov v folije. Ustrezna termomehanska obdelava spremeni sestavo v mikrostrukturnih fazah in s tem njihov vpliv na statično rekristalizacijo, kar vpliva na kvaliteto površine in mehanske lastnosti folij.

V delu smo določili optimalno sestavo in predpisali procesne parametre kontinuiranega ulivanja, pri katerih je liti trak možno uporabiti kot surovino za izdelavo tanke pločevine in izolacijskih, konvertorskih in gospodinjskih folij standardne kakovosti.

Ključne besede: kontinuirno litje Al-trakov, izdelava tanke pločevine in folij, razvoj mikrostrukture, fazna sestava in preoblikovalnost litih trakov

1 INTRODUCTION

One of the goals of Impol's rolling modernization program is to focus production on converting, household and insulation foils.[1] Foil is a high-added-value product if manufactured from in-house raw material [2,3]. That is why Impol has opted for foil production based on 6-mm-thick cast strips with broad widths (from 900 mm to 1700 mm) as raw material.

The basic challenges that Impol wishes to deal with in the proposed project are mastering the new technology, the use of continuous cast strip for making high-quality foil and the broadening of its marketing possibilities with final products of new quality.

At this stage of the new technology implementation and the restructuring of the roll casting programme it was essential (i) to develop and master new knowledge in the field of developing cast strip properties (roughness, oxide impurities, etc.); (ii) to modify the chemical composition of the alloys for continuous casting and to unify various alloys into a few suitable compositions for continuous casting, without affecting the properties of final products, which is very challenging in terms of technology; (iii) to develop the microstructure, phase composition and formability of cast strip as well as final products (firstly, 8–10 µm gauge insulating, converter and household foils); and (iv) to continue the development of new products/applications from cast strip.

The introduction of continuous casting of thin aluminium strip based on AA 1050 and AA 8011 causes a fundamental change in the microstructure and therefore the physical and chemical properties of the material when compared to the conventional working of DC or semi-continuous cast slabs [4-8].

During water-cooled rolling, due to the increased speed of crystallization and simultaneous hot rolling in the semi-solid state, the a solid solution is strongly oversaturated and the non-equilibrium intermetallic phases Al_mFe and $Al_xFe_ySi_y$ are precipitated. The composition, the distribution, the size, the shape and the fraction of the microstructural constituents have a crucial effect on the formability of these alloys and the final quality of the foil. The presence of a fine-grained oxide in the metal at the strip surface, the size and orientation of the solidified grains and the central segregations all affect the grain size and macroporosity [4,6]. Relaxation processes are slower because of the shorter free path for dislocation sliding during cold working because of the greater number of precipitates in the continuous cast alloys.

Understanding how the interrelationship between important alloying as well as trace elements (Si, Fe, Mn, Cr, Zn, Ti) in the based aluminium space lattice affects their solubility makes it possible to change and optimize the chemical composition of aluminium alloys 1050 and 8011, achieving in that way the standard and comparable quality of foil stock suitable for further downstream processing.

The project objective was to understand the processes and determine the evolution of the microstructure of rapidly solidifying aluminium alloys (1050 and 8011) cast in Impol's new caster in order to enable the faster development and implementation of new alloys with the aim of expanding the range of products made from continuous cast thin strip. By knowing the effect of the continuous-casting process parameters, by optimizing and unifying alloys and by understanding thermo-mechanical processes we can expect to be able to change sufficiently the microstructure and the chemical composition of the existing phases and thereby the technological properties and quality level of foil made from continuous cast strip in such a way as to get a favourable response in the market. The new knowledge gained about the material will furthermore serve as a basis for describing foil properties and their comparison with foil made from hot-rolled strip manufactured from conventional semi-continuously cast slabs.

2 EXPERIMENTAL PROCEDURES

The R&D activities are composed of two main parts:

- Strip production on caster,
- Foil production from caster strip

2.1 Strip production on twin-roll caster

The activities were divided into four phases, with each phase corresponding to one of the casting widths of Impol's production program (1050, 1150, 1600 and 1700) mm. Each phase covered the following: defining the casting parameters, developing the casting operator's ability and autonomy to produce material under stable casting conditions, improving the cast strip's geometry (longitudinal gauge variations over the coil length below ±2%, longitudinal gauge variations over one roll revolution below ±1%, cross profile between 0 and 1%, tilting between two edges limited to 1%), and improving the cast strip's surface quality, taking into account the feedback from the rolling mill regarding the end products (foil production).

2.2 Foil production from the caster strip

For the whole foil production program (final gauge from 0.006 mm to 0.100 mm), some representative final thicknesses and widths were chosen. The suitability of the technological procedures for all the foils in the thickness range from 0.006 mm to 0.100 mm was assessed based on the approval of the technology and the process for foil production, and on the approval of quality by customers for the chosen representative final thickness and width. The approval of the caster strip quality and technology/process for foil production was also performed for all the chosen widths using alloys AA 1050, AA 1200, AA 8011 and AA 8079.

3 RESULTS AND DISCUSSION

3.1 As-cast microstructure of strips

The as-cast microstructure of the strips was monitored in the longitudinal and the transverse cross section at the mid-with (**Figure 1**) as well as at the mid-thickness (**Figure 2**) of the coils AA 1200.

It has been shown that in the selected casting parameters a cast strip of good quality was obtained. In particular, the cast strip had a very fine microstructure, typical of strip casting at 6 mm with appropriate grain-refiner addition, a small centerline segregation, similar to that in the cast strip of competitors, no hard phases (that could lead to porosity problems), and no surface segregations.

3.2 Foil production

Fabrication schedules through to the 8–9 μm gauge have been developed for the downstream processing of strips of AA 1050, AA 1200, AA 8011, AA 8079 and AA 8006. These schedules were field tested during industrial trials at the Impol Rolling Mill, where foils are produced from both hot-rolled foil stock and as-cast strips.

3.3 Trials with the AA 1050 alloy for insulation foil products (final gauge 70 μm)

The main results are:

- 1st trial: non proper strip-surface aspect with longitudinal lines,
- 2nd trial: acceptable strip-surface aspect, similar to hot-rolled material,
- 3rd trial: acceptable strip-surface aspect, similar to hot-rolled material.

It has been determined that the poor surface aspect obtained with the coils of the 1st trial was mainly due to a large as-cast grain size resulting from an insufficient addition of grain refiner (large feathery grains were observed at the strip's mid-thickness). This was solved during the 2nd and especially the 3rd trial by increasing the grain-refiner addition from 1.0 kg/t to 1.6–3.0 kg/t.

3.4 Trials with AA 1200 and AA 8011 alloys for foil products (final gauge 8 μm):

The surface quality of the mat side at the final gauge was the most important parameter to be controlled.

A correlation between the surface aspect of the mat side and the grain size of the foil was found. The same correlation was established for the 0.6 mm OH after intermediate annealing.

The results obtained can be summarized as follows:

- The foil from the reference caster material has the finest grain size at the final gauge and after intermediate annealing
- Regarding the AA 1200 alloy, the foil with the Fe/Si ratio 1:1 from the 2nd trial, the grain size was small, both at the final gauge and after intermediate annealing (without any large surface grains). The grain size was, however, slightly larger than in the foil from the reference caster material. The foil with the Fe/Si ratio 2:1 from the 2nd trial has larger grains at the final gauge and large surface grains are observed after intermediate annealing. The foil with the Fe/Si ratio 2:1 from the 1st trial has numerous large grains, both at the final gauge and after intermediate annealing.
- In the case of the AA 8011 alloy, the foil from the 2nd trial has a slightly larger grain size at the final gauge than the foil from the 1st trial. The material from the 2nd trial also has a few large surface grains after intermediate annealing

It was found that the Fe/Si ratio 1:1 (the same ratio as in the reference caster material) for foils made from the

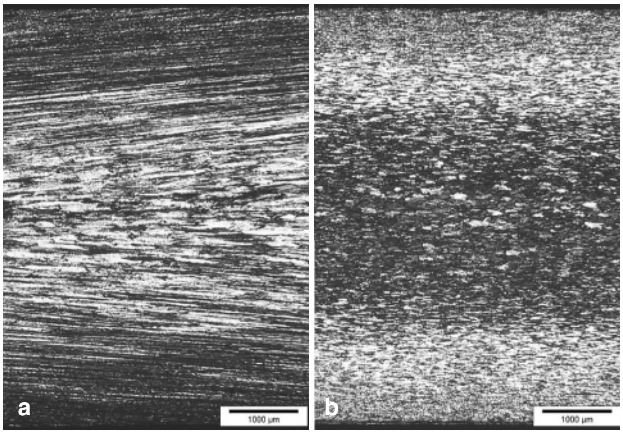

Figure 1: As-cast microstructure observation: (a) in the longitudinal and (b) in the transverse cross section at the mid-width of the AA 1200 coil

Slika 1: Mikrostruktura prečnega preseka sredinskega vzorca litega traku na osnovi AA 1200: (a) vzdolžno in b) prečno na smer valjanja

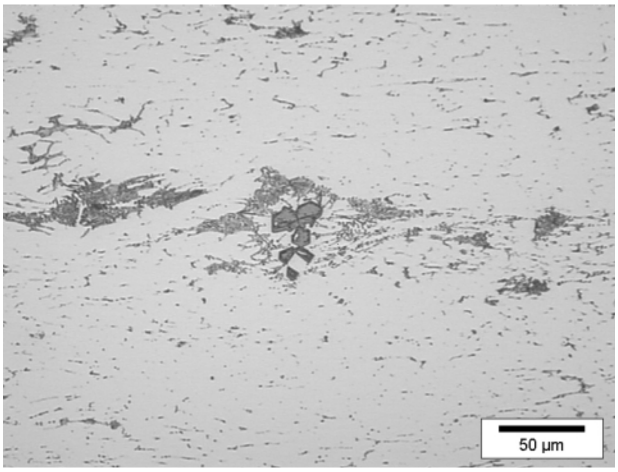

Figure 2: As-cast microstructure at the mid-thickness of the coil AA 1200

Slika 2: Mikrostruktura površine sredinskega vzorca litega traku na osnovi AA 1200

AA 1200 alloy gave a better surface quality for the final product. In addition, the increased grain-refining level was the key to the improved mat side surface aspect in the 2nd and 3rd trials.

Taking into account the foils from the AA 8011 alloy, the slightly lower mat side quality of the 2nd and 3rd trials compared to the 1st trial might be due to the higher casting speed. A possible explanation is that the casting speed affects the solidification front, the segregation regime of the alloying elements, and therefore the distribution of the recrystallisation nuclei.

3.5 Suitability of Impol caster material for foil downstream processing

- **Isolation foil (70 μm):** Alloy 1050 is suitable for the production of isolation foil, using the Impol standard processing route (no homogenizing). The quality obtained (especially the surface aspect) is comparable to that of the hot-rolled material
- **Technical foil:** Alloy 1050 is suitable for the production of technical foil, using the Impol standard processing route
- **Household foil (10 μm):** Alloy 8011, processed with the Impol standard route is suitable for the production of household foil
- **Converter foil (8 to 10 μm):** Alloys 1200* and 8011 processed via a route with homogenizing are suitable for the production of converter foil.
- **Blister foil (about 20 μm):** For this specific case, thermostability is a key property. For alloys 1200 and 8011 processed via the Impol standard route, the thermostability is within the specifications. Depending on the surface-quality requirements, a specific processing route will probably have to be defined for this foil product
- **Porosity (general comment for all foils):** Porosity from Impol caster material is usually of a low level, well within the specifications, except in some cases. A sufficient proportion of ingots must always be used in the furnace charge (at least 50 to 70%) for coils production and the filtration of a molten metal could be increased

4 CONCLUSIONS

- Complete casting parameters for strip production on the Jumbo 3CM Impol caster were defined and approved for alloys: AA 1050, AA 1200, AA 8011, AA 8079.
- Various strip downstream processing routes for foil stock and foils production were tested at the level of industrial trials.
- Based on this, several process modifications were introduced, resulting in significant quality improvements of as-cast strip, foil stock and foils.
- Insulation, converter and household foils of standard quality in gauges between 8 μm and 70 μm were produced and foil production technology for these target products was successfully implemented.
- An ambitious program of thin gauge 6.35 μm foil production development is planned for the months to come, which will allow Impol to come even closer to meeting its customers' needs.

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