Economic and social aspects regarding mathematical models in aluminum alloy technology

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Abstract. Aluminum and aluminum alloy usage has a great economic and social importance. Therefore, so customary in our lives, aluminum and its alloys have a great spread in various fields. Our paper presents possibilities for optimization of aluminum (Al) alloys elaboration and casting processes by specific mathematical modeling. Some of these developments might include: developing new furnace types that will replace the largely exposed melt surface with a reduced surface area, thus improving energy consumption, environmental performance and overall efficiency through reduced metal loss; the development of in–line metal treatment units through high speed degassing. Direct and reliable detection and measurement techniques of non-metallic measurements will be developed; continuous production processes will replace sequential operations used to produce tin foil, extruded products and remelted alloyed ingots. We also present the main modeling principle and we describe the algorithm of modeling. Recycling provides a viable solution to existing shortages of raw materials. The use of products made with secondary aluminum provides high energy savings compared to the same products that use primary aluminum. Recycling aluminum products has a positive impact on the environment, its recyclability being preferred over other materials. An important principle of mathematical modeling is the principle of analogy. This principle consists in observing and analyzing competently the modeled reality, using both analogy with other fields of research and logical homology.

Keywords: economic, social, mathematical modelling, Al alloys technology.

JEL Codes: C6, C9, O3

1. Introduction

Economic and social aspects regarding mathematical models in the field of technologies specific to aluminum alloys have a great importance for our existence.

A property of aluminum and aluminum alloys, with direct economic and social benefits is corrosion resistance. This is due to a protective oxide layer. For example, resistance to the chemical action of nitric acid, this being reflected in the manufacture of nitric acid conveyors.

Aluminum sheets, considered materials of the future, can be manufactures using various types of surfaces, such as: ribbed, perforated, expanded.

Aluminum and its alloys have a great social and economic importance. Therefore, many fields of usage for these non-ferrous metallic materials confers them a great role in our economic and social life.

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Aluminum represents a vital resource for the future. It can be connected with a wide range of sectors, from transportation to food packaging. It also has considerable importance in the field of health and health safety.

The use of low density Al in car construction improves traffic safety, while Al packaging helps prevent food alteration.

While in 1950 total aluminum exports from the U.S. were less than 1.1 million tons, in 1996 total U.S. exports totaled about 10 million tons. In North America, secondary product recovery increased from 25% to 35%, while imports increased from 15.5% to 27%, comparing with the metal provided from 1950 to the present day.

Waste consumption in the U.S. totaled 310 tons in 1948, while today it is more than 3.9 million tons/year, which includes the recovery of over 63% of the delivered and recycled beverage cans. Aluminum content in car parts that have been recycled in the year 2000 totaled 560 tons.

As [1] “Direct Chill (DC) casting is a well-established process in the production of aluminum ingots and is used word wide by the aluminum producing industry. DC casting involves a range of coupled physical phenomena that must be represented appropriately if any process model is to be sufficiently comprehensive.”

Recycling provides a viable solution to existing shortages of raw materials. The use of products made with secondary aluminum provides high energy savings compared to the same products that use primary aluminum. Recycling aluminum products has a positive impact on the environment, its recyclability being preferred over other materials.

There has been a change in the direction of development in the aluminum industry in recent years. The goal is not only to increase the quantity of sold metal, but also to use the basic knowledge of industrial materials that have specific applications, thus satisfying demand.

Aluminum casting can be improved in several ways in the foreseeable future. Some of these developments might include:

- Developing new furnace types that will replace the large exposed melt surface with a reduced surface area, thus improving energy consumption, environmental performance and overall efficiency through reduced metal loss.
- The development of in-line metal treatment units with high speed degassing. Direct and reliable detection and measurement techniques for oxides measurements will be developed.
- Continuous production processes will replace sequential operations used to produce tin foil, extruded products and remelted alloyed ingots.
- Energy and environmental considerations will continue to encourage the substitution of denser cast materials with aluminum. The U.S. Council for Automotive Research will greatly improve safety and capability of molded components.
- Furnaces melt treatment and casting operations will be fully automated.
- New casting processes, such as low hydraulic and electromechanical pressure, air injection and so on, will be developed in order to improve surface quality, structure and uniformity in cast parts.

About quality of aluminum Direct-Chilled (DC), as [2] “The surface quality of direct-chilled (DC) cast aluminum rolling sheet ingots is often reduced by a segregated layer of exudations. The exudated layer is caused by interdendritic melt flow through a partly solidified (mushy) and remelting shell close to the mold. This remelting and the resulting metal flow are due to an air gap between the shell and the mold caused by the global solidification contraction of the ingot.”

An important principle of mathematical modeling is the principle of analogy [3, 4]. This principle consists in observing and analyzing competently the modeled reality, using both analogy with other fields of research and logical homology.
2. Economic and social aspects regarding mathematical models in the field of aluminum and aluminum alloys specific technologies

Applying mathematical models specific to aluminum industry and its alloys has the following economic and social advantages:

- Economic efficiency of aluminum production and its alloys, with positive consequences regarding lower production cost.
- Rising product quality and optimizing quality/price ratio
- Improving social terms regarding aluminum and aluminum alloy usage

In figure 1 we present the economic and social advantages of mathematical models usage in aluminum and aluminum alloy production.

![Fig. 1. Economic and social advantages of mathematical models usage in aluminum and aluminum alloy production](image)

About social aspects, in figure 2 we present Innovation Groups Adoption (IGA).

![Fig. 2. Innovation Groups Adoption (IGA)](image)

The consumers who eventually accept an innovation can fall into the five groups (figure 2). The main characteristics of the five groups of consumers are:

- Innovators – the first to buy and use new products.
  - The innovators are clearly critical to the process of adoption, including financial – economic adoption.
They are likely to communicate with and persuade others to try the product, including financial–economic product.

3. About modeling principle

According to principle of analogy, for mathematical models making were used the following steps:

- the modeled subject definition – represents the first phase of the modelation analysis. This step must satisfy both the purpose and the simultaneous system’s aims, ensuring their compatibility;
- the efficiency criteria’s definition – is a step imposed on the correct definition of the system’s aims and allows the optimization of the modeling solutions;
- making the options – basing on accessing some realistically, original and efficient solutions;
- choices evaluating – related to the established efficiency criterials;
- choosing the final solution – based on the analysis between the different solutions of the modeling.

Another important principle of modeling is the principle of concepts. This principle is based on the systems’ theory, including the feedback concept.

The principle of hierarchization consists of making a hierarchical model system, for structuring the decision and coordinating the interactive subsystems.

The modeling system’s central element of the aluminum alloys melting and casting processes consists of the system’s criteria function \([3, 4, 5]\).

Knowing that the technological processes study for EAF is subordinated to high quality Al alloys production, the modelling system’s criteria function \((CF)\) is the ratio between quality and price \([6]\):

\[
CF = \frac{QUALITY}{PRICE}_{max}
\]  

(1)

The maximum of the criteria function is assured by the mathematical model of prescribing the criteria function.

The mathematical model has the following goals:

A. Determining the dependence between the main alloying elements concentration and the thermodynamic conditions on the basis of mass transferring modeling (with its diffusive and conductive elements).

B. Determining the speed area and the system’s turbulence characteristic.

4. Description of algorithm

The scheme of the system that blows the reactive powder into the liquid Al alloys is presented in figure 3. The three-phased area refer to: spurt of inert currying gas (bubbles), solid particles (reactive powder) and liquid Al alloys.

The modeling algorithm main stages are:

1. Continuity law:

\[
\frac{1}{x} \frac{\partial}{\partial x} \left( \rho_x \cdot v_x \right) + \frac{\partial}{\partial y} \left( \rho_y \cdot v_y \right) = 0
\]  

(2)

Where: \( \rho_x, \rho_y \) – are the densities of the afferent environment of the area in the radial direction \(x\), respective longitudinal \(y\);

\( v_x, v_y \) – are the radial (in the \(x\) direction) and the longitudinal (in the \(y\) direction) components of the velocity.
Evidently:

1. For $x > r_{3,l}$, $\rho = \rho_{Al\, alloy}$
2. For $x < r_{3,l}$, $\rho = d_i \rho_{gas} + (1 - d_i) \cdot \rho_{Al\, alloy}$

Where $d_i$ is the phases distribution parameter given by relation:

$$d_i = \frac{Q_{gas}}{2 \pi \int_0^r v_x \, dx}$$

Where $Q_{gas}$ is the blown rare gas flow (m$^3$/h)

2. The movement law in the radial direction $x$:

$$\frac{1}{x} \cdot \frac{\partial}{\partial x} \left( \rho \cdot x \cdot v_x^2 \right) + \frac{\partial}{\partial y} \left( \rho \cdot v_x \cdot v_y \right) = \frac{1}{x} \cdot \frac{\partial}{\partial x} \left[ x \cdot \mu_{ef} \frac{\partial v_x}{\partial x} \right] +$$

$$+ \frac{\partial}{\partial y} \left[ \mu_{ef} \frac{\partial v_x}{\partial y} \right] = - \frac{\mu_{ef} \cdot v_x}{x^2}$$

Where: $\mu_{ef}$ – is the real viscosity, which is calculated with:

$$\mu_{ef} = \mu_m + \mu_t$$

In which: $\mu_m$ – is the molecular viscosity;
$\mu_t$ – is the turbulent viscosity.

The turbulent viscosity can be calculated on the basis of the model:

$$\mu_t = \frac{K}{\sqrt{W}}$$

Where: $K$ is the kinetic turbulent energy of the fluid; $W$ is the frequency of the turbulent fluctuation.

3. The movement law in $y$ direction

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**Fig. 1. Scheme of the Al alloys mathematical modeling**

1 – Liquid Al alloy area; 2 – Liquid slag area; 3 – Three-phased area.
\[
\frac{1}{x} \frac{\partial}{\partial x} \left( \rho_x \cdot v_x \cdot v_y \right) + \frac{\partial}{\partial y} \left( \rho \cdot v_y \right) = \frac{1}{x} \frac{\partial}{\partial x} \left[ x \cdot \mu \frac{\partial v_y}{\partial x} \right] + \\
+ \frac{\partial}{\partial y} \left[ \mu \frac{\partial v_y}{\partial y} \right] + \rho \cdot g
\]

(9)

Where "g" is the gravity acceleration.

4. Determining the speed potential’s transport law \( p_v \):

\[
x^2 \cdot \left[ \frac{\partial}{\partial y} \left( \frac{p_x}{x} \cdot \frac{\partial f_c}{\partial x} \right) - \frac{\partial}{\partial x} \left( \frac{p_x}{x} \cdot \frac{\partial f_c}{\partial y} \right) \right] - \\
- \left[ \frac{\partial}{\partial y} \left( x^3 \cdot \frac{\partial}{\partial y} \left( \mu \frac{p_x}{x} \right) \right) + \frac{\partial}{\partial x} \left( x^3 \cdot \frac{\partial}{\partial y} \left( \mu \frac{p_x}{x} \right) \right) \right] = 0
\]

(10)

5. Determining the current correlation:

\[
\frac{\partial}{\partial y} \left[ \frac{1}{\rho x} \cdot \frac{\partial f_c}{\partial y} \right] + \frac{\partial}{\partial x} \left[ \frac{1}{\rho x} \cdot \frac{\partial f_c}{\partial x} \right] + p_v = 0
\]

(11)

5. Conclusions

Aluminum and aluminum alloy usage has a great economic and social importance. The phenomenon of transport on radial direction are emphasized in the superior area of the recipient, which is suggested by the higher values of the speed component on this direction: \( v_x = 0.4 \text{ - } 0.6 \text{ cm/s}. \) In this way, favorable conditions are settled for a good fluid shuffle.

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Assuring a relatively high value of the longitudinal component of the velocity in a sensitive size area: \( v_y = 1.2 \text{ - } 2.5 \text{ cm/s}, \) which leads to good Al alloy’s recycling.

The resulting velocities’ field (\( v \)) assures maintaining continuous injected fluids and the reaction products’ acceleration. Creating and maintaining this velocities regime and, therefore, the continuous areas of transport of the liquid Al alloys are ensured by the mentioned injection parameters.

6. References (Endnotes)


