CREATING AN ANALYSIS MODEL OF THERMAL CONDUCTIVITY FOR Al6061 ALLOY USING ARTIFICIAL NEURAL NETWORK

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With the help of an ANN (Artificial Neural Network), this paper has created a mathematical-simulative model of thermal conductivity analysis for Al6061 alloy. With the help of mathematical equations for conductivity the result is a chart of thermal conductivity variation, important for the implications the chemical composition of Al6061-T6 alloy has over mechanical properties and elaboration temperature. This correlation between mechanical properties and simulative numerical modeling has a great importance for establishing without additional costs and wasted time the correct destination for an elaborated product but also improving certain characteristics of the alloy based on its destination.

Keywords: Artificial Neural Network, Al6061, Thermal conductivity, Mathematic model

1. Introduction

The majority of new techniques developed in the industry of aluminum are sometimes meant to create special products which themselves need a thorough investigation of the alloy proprieties, with loss of time and high financial expenses. Finally, the new techniques cannot predict or simulate the required microstructure, optimal parameters or composition of alloy to improve the processes that include A16061. Most improvements of mixed metal A16061 (series A16xxx) are highly bonded by their mechanical proprieties (whom depend also of their microstructural characteristics). This way, simulative methods of process-structure-proprieties with alloy A16061 can be used with appreciable results on the physical-mechanical or on the recycling process.

An important role in obtaining the wanted alloy with the desired physical-mechanical characteristics is thermal treatment. It is important to know that

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thermal treatment solutions are needed for establishing the characteristics of the alloy and also to optimize process parameters in accordance with a specific target.

In the European Union there is a big number of aluminum alloys, each with its own structure that may apply simulative-predictive techniques like Artificial Neural Network (ANN). ANN applicability idea is to adjust process parameters and composition on alloy A16061 to obtain a separate combination which can be widely used.

In this paper, ANN is used in concordance with mathematical models to predict thermal conductivity variation and to establish a variation model for the A16061-T6 alloy.

Aluminum is an important element with a complex applicability in national or international level industries. Aluminum 6061 is widely used for different applications due to its proprieties: density 2.71g/ cm^3, Young's modulus: 68.9GPa, Poisson's Ratio: 0.33µL. It is the most common type of Aluminum used in industry, even though it is divided in more categories: 6061, 6061-T4, 6061-T6 (each one having physic-mechanical proprieties that differ depending on elaboration and destination). The ultimate tensile strength is at a point of 300MPa, its elongation is equal to 8%, it has a conductivity of 77^{o}F at 152W/m·K and up to 100MPa fatigue limit.

Aluminum 6061 is used for creating different aircrafts parts (wings, fuselage), airplanes; sometimes Al2024 is more resistant, but Al6061 has a better workability and a higher corrosion resistance. It is also used in construction of yachts, boats, locomotive parts, train wagon parts, bicycle parts, fishing items.

2. **ANN** modeling

The usage of ANN implies defining the relation between proprieties of alloy proprieties Al6061-T6, alloy composition and process variables. ANN is generally characterized by architecture, activation functions, algorithms, therefore to use this method you must consider: ANN structure, algorithms used and transfer functions.

In order to describe the ANN model, it may be required to consider placing a black box data which by certain criteria would provide information in correlation with the line: processes-structure-proprieties. ANN structure is characterized by the number of entries and the number of neurons in each entry (Fig. 1) as a whole. Simplified ANN consists of: data entry, hidden data (processing) and data output.

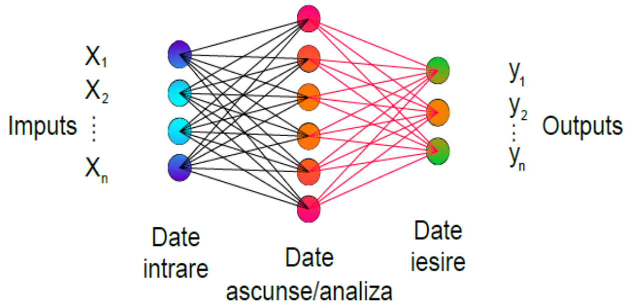

Fig. 1. General architecture of ANN

Table 1

ANN parameters for Al6061

Input Parameters for the 6xxx series									
Major alloying elements					Others				
Alloying element	Mg	Si	Cu	Zn	V	Ti	Fe	Mn	Cr
Number of alloys containing this element	40	30	21	14	0	12	16	13	12
Range, (%weight)	0-1.4.	0-1.8	0-1.2	0.0.25	0	0-0.2	0-0.70	0-1.1	0-0.5

Modeling and simulating ANN for the Al 6061-T6 alloy requires certain steps: collecting data, processing collected data, ANN training, testing the ANN training model and predicting the simulation using the already-built ANN models.

It is also important to limit the errors which occur due to input data-related approximations and adjustments, and the whole process is repeated until an acceptable, error-free criterion or function is attained. In ANN a valid function transforms the input data in output values (which, basically, have a linear variation $y = ax + b$).

The input parameters necessary to study the process-structure-properties system for Al6061 refer directly to the chemical composition, quantity, combination of alloying elements. For each element of Al6$x_1x_2x_3$ series, the first digit 6-indicates the series, $x_1x_2x_3$-the alloying element modified in an existing alloy, x_2x_3-special alloying elements.

The major alligation elements for the Al6061-T7 are Mg and Si, and the chemical composition of the analysed alloy is presented in Table 1. The physical and plasticity characteristics are highlighted in Table 2. They are taken from various specialty articles, analysed and used in simulation.

Table 2

Physical and elastic parameters of Al6061-T6

Al6061	**Elastic**			**Physical**							
	E	G	v	T_{sol}	T_{liq}	Cp	a	ρ	ρ_{el}	λ	EC
6061-T6	70000	26300	0.33	580	650	895	23.3	2700	40	166	43

where:

E - Elasticity module; [MPa]

G - Rigidity module; [MPa]

ν - Poisson's module [-]

T_{sol} - Solid temperature; [°C]

T_{liq} - Liquid temperature; [°C]

C_p - Specific capacity; [$Jkg^{-1}K^{-1}$]

a - Thermic expansion coefficient; [$\mu m\ m^{-1}K^{-1}$]

ρ - Density; [$kg\ m^{-3}$]

ρ_{el} - Rezistivity; [nΩ m]

λ - Thermal conductivity; [$Wm^{-1}K^{-1}$]

EC - Electrical conductivity; [%IACS]

3. Aplicability of the mathematical model based on ANN

In order to study this problem, it is needed to consider a bi-dimensional environment on a Ω domain, bordered by a Γ surface inside of which an estimate the thermal conductivity value is made. The mathematical model of the heat transfer could be:

$$\nabla(\rho(x,y)\nabla T(x,y,t)) = \frac{\partial T(x,y,t)}{\partial t} \quad \text{inside of } \Omega \tag{3.1}$$

with the following conditions:

$$\begin{aligned} T(x,y,t) &= T_0(in\Omega) \\ T(x,y,t) &= T_\Gamma(in\Gamma) \end{aligned} \tag{3.2}$$

For $t \in \lfloor 0, t_f \rfloor$ and where $\rho(x,y)$ is the thermal conductivity, T_0 initial temperature, T_Γ bordered area temperature. Measuring the temperature can be done by measuring different points and within different intervals on the Γ area of the Al6061 alloy. The mathematical analysis model is presented in Fig. 2 and contains the Γ domain, the Ω bordered area, the analyzed interval of the thermal conductivity [-0.5 ;0.5].

$$
\begin{array}{llll}
t_1 & T_{11} & \ldots\ldots\ldots & T_{1Q} \\
t_2 & T_{21} & \ldots\ldots\ldots & T_{2Q} \\
 & \ldots\ldots\ldots\ldots\ldots\ldots & & \\
t_p & T_{p1} & \ldots\ldots\ldots & T_{pQ}
\end{array}
$$

where P and Q are the number of steps and measuring points of temperature used for establishing the model.

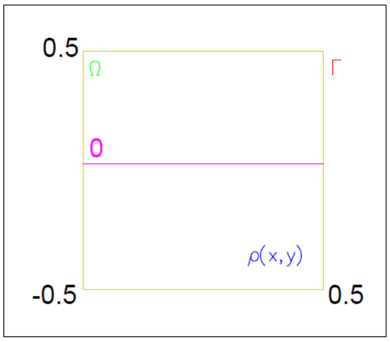

Fig. 2. Mathematical analysis model of the thermal conductivity

Relative errors can be described using:

$$E[\rho(x,y)] = \frac{1}{pQ} \sum_{i=1}^{p} \left(\sum_{j=1}^{Q} \left(T(x_j, y_j, t_i) - T_{ij}\right)^2 \right) \tag{3.3}$$

All the values and errors are taken into account after the triangular model with 1776 elements, 970 nodes in 22 steps. Spaces are defined:

$$\Omega = \{(x, y), |x| \leq 0.5; |y| \leq 0.5\}$$
$$\Gamma = \{(x, y), |x| = 0.5; |y| = 0.5\} \tag{3.4}$$

a first variation of artificial temperature results:

$$\rho(x, y) = x^2 + y^2 \tag{3.5}$$

Therefore, pre-defining the mathematical variation model of $\lambda = 166\,\mathrm{Wm^{-1}k^{-1}}$ with $\rho = 0.5$ is possible. The variation charts are presented in Fig. 3. The system used for the simulation is composed of: CPU: AMD A8-6600K 4.2GHz, 8GB RAM DDR3 1600MHz, GTX 750Ti-2GB DDR5 video.

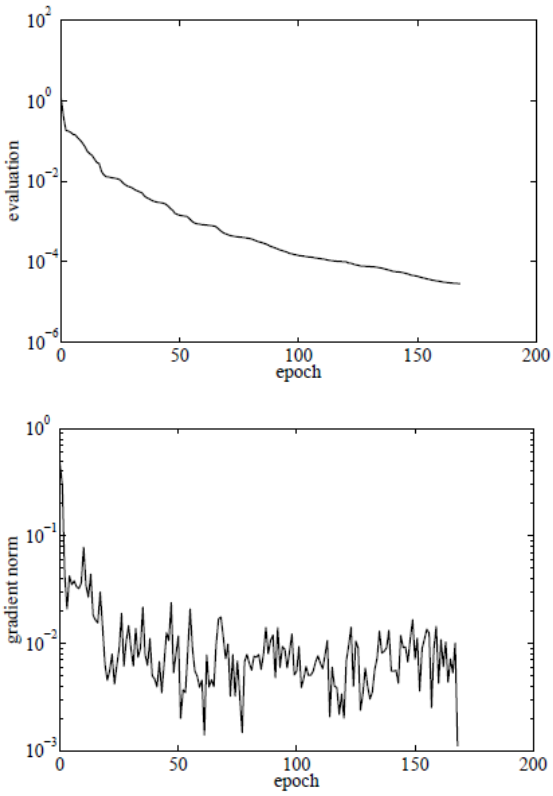

Fig. 3. Thermal conductivity evolution according to the studied model. Thermal conductivity gradient evolution

The final analyzed model can be expressed, taking into account all the previous relations, therefore:

$$\rho : R^2 \to R, (x, y) \to \rho(x, y, \alpha)$$
$$\rho(x, y, \alpha) = b_1^{(2)} + \sum_{j=1}^{3} w_{1j}^{(2)} \cdot \tanh\left(b_j^{(1)} + w_{j1}^{(1)} x + w_{j2}^{(1)} y\right) \tag{3.6}$$

and so the equality relation becomes:

$$\rho^*\left(x, y.\alpha^*\right) = 61{,}6455 + 47{,}7723 \tanh(-0{,}551 - 0{,}146x - 0{,}100y) -$$
$$32{,}2139 \tanh(0{,}74 - 0{,}25x + 0{,}100y) - 20{,}8 \tanh(0{,}76 - 0{,}005x - 0{,}43y) = \tag{3.7}$$
$$= \lambda = 166 Wm^{-1}k^{-1}$$

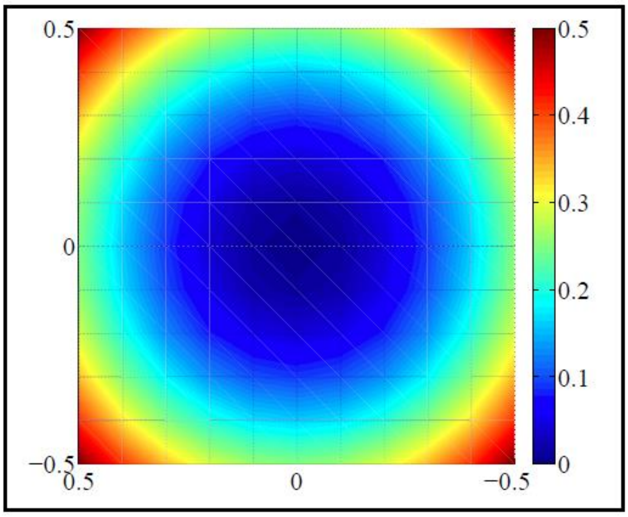

Fig. 4. Results of the ANN thermal conductivity test for the used model.

Fig. 3 presents under computerized form the analysis relation of a model according to which ρ=0.5 represents the maximum value on a bordered area which can obtained as an equivalent maximum value $\lambda = 166\,\mathrm{Wm^{-1}k^{-1}}$. The visual interpretation is found in Fig. 4, on which it is observed a maximum value of thermal conductivity, at extreme values of bordered area for a parallelepiped rectangular body from Al6061.

3. Conclusions

The paper above has analyzed a mathematical model for expressing thermal conductivity through ANN developing the following conclusions:

1) Based on the type of alloy, in the case of Al6061, the surface and structural-geometrical form of the piece is important to approximate the value of thermal conductivity on that specific surface.

2) The values for a side face section of the bar of Al6061 are presented in Fig. 3 and the highest values are at the extremities, therefore the (3.7) analysis formula can be applied for a wide range of pieces, but for a higher complexity of geometrical surfaces it must be updated.

3) There is a close link between the thermal conductivity problem and other mechanical properties in the study of Al6061 alloy that is why it is important to mention certain physical parameters using ANN with the purpose of saving financial resources and time.

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