Neural network analysis for the solidification scheme of the recycled metal casting

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Abstract: The use of recycled materials as one of the great results for the industrial raw materials shortage may face serious problems during the mold casting process. This paper researches the difference in solidification step between the edges and the center of the aluminum recycled cast. The implementation of such research passes through two verification steps; the removal of the chemical dyes and then to melt the recycled aluminum cans in a ceramic container in order to produce the metallic 60 x 13cm mold. Six thermocouples are inserted on the casting edges and the center and liked directly to a computer system in order to simultaneously record the temperature readings from the start of the cooling/solidification process. The Artificial Neural Network ANN approach is applied to the recorded data via the utilization of the software MATLAB in order to analyze the cooling curves and determine the mathematical representation of the solidification layers through the casting. The interior layers microstructure is examined via SPECTROPORT mobile metal analyzer so as to detect the solidification trend through the examined ingots. The edges of the casting are shown to solidify more quickly than the central region and also it is demonstrated via the microstructural samples that the boundaries are more clear in the center than these at the edges.

1. Introduction
The increasingly raised rate of the raw materials consumption in order to satisfy the various industries and their related high cost has made it so urgent to scout alternate resources or ways for that sake. Recycling was one of the primary solutions that made big success and boosted the researches in order to improve the results whether in the physical or chemical properties of the final product. As the melt and re-mold of ferrous and non-ferrous materials, are the most used recycling methods and their handling plays a critical role in that regard, many studies have been focused on their very details. Heaney, 2012 combined the most useful powder metallurgy features and injected plastic molding in order to assist in producing lesser, complex-shaped metal components with good mechanical properties [1]. Computer-aided approaches and analyses were also used in order to make a better understanding of the theory and practice of molding and casting of the mentioned materials, whether raw or recycled and create and optimize fundamental castings [2]. Recycled aluminum has found a great interest as it serves a great input for a wide range of industrial uses starting from beverages canning to aircrafts manufacture. It is assumed that by 2020 aluminum request is projected to increase to around 97 million tons (with about 31 million tons recycled from the scrap) [3]. The aluminum commercial cans are widely used in variety of sizes, shapes and they share a great percentage of the content of municipal and industrial solid waste that is hardly biodegradable with a million-year half-life, would cause serious environmental problems [4], while they may serve as a great supply for the...
various commercial and industrial uses for their high aluminum content as demonstrated by table 1. The solidification of the microstructure of aluminum alloy cast is significantly related to the cooling rate. Increasing the cooling rate, may lead to the disappearance of the needle-like \( \beta \)-Al\(_{5}\)FeSi phase, and boost the development of the Chinese scripts \( \alpha \)-Al\(_{15}(\text{Fe, Mn})3\)Si\(_2\) phase. Also, increasing the cooling rate proportionally increases the nucleation temperature of the \( \alpha \)-Al dendrite and lessens the Al-Si and Al-Cu phases eutectic [5].

Table 1. The aluminum can body’s chemical composition [6].

| Composition | Cu% | Fe% | Mg% | Mn% | Si% | Zn% | Al% | Others |
|-------------|-----|-----|-----|-----|-----|-----|-----|--------|
| ISO,AlMn1Mg1 | ~0.25 | ~0.70 | 0.8-1.3 | 1.0-0.5 | ~0.3 | ~0.25 | 95.5-98.2 | ~0.25 |
| A1 3104-H19 | 0.050-0.25 | ~0.80 | 0.8-1.3 | 0.8-0.4 | ~0.6 | ~0.25 | 95.0-98.4 | ~0.15 |
| AA5182-H19 | ~0.15 | ~0.35 | 4-5 | 0.2-0.5 | ~0.2 | ~0.25 | 93.2-95.8 | ~0.15 |

A neural network is a vastly analogous dispersed processor that involves simple handling units of a natural affinity for credible realistic knowledge to serve the various needs. Artificial neural network (ANN) is a sort of Artificial Intelligence technique that impersonates the human brain’s performance [5]. Unlike the other statistical methods, ANNs are able to model the linear and non-linear systems without the necessity to implicit assumptions, and hence they were applied by various scientific and engineering aspects [7, 8]. The two main groups of ANNs are the feed-forward and the feedback or recurrent networks. In the first one, there are no loops to be formed by connections of the network, whereas one loop or more could be in the second. The layered network is furthermore frequently used family of feed-forward networks where neurons are planned into layers with firmly one-directional associates from one layer to another [9-11].

This paper seeks the determination of the analytic method for the center to edges thermal behavior during the solidification stage of a recycled aluminum cast via the neural network approach in order to proceed for an optimal final product.

2. Experimental procedure

The collected waste aluminum cans; food, beverages and other various uses, need to be thoroughly shredded by the use of BLT mini aluminum cans shredder, to produce tiny fragments that would pass through a gas-fired oven in order to eradicate any coating materials; dye or polish. The melting process comes then via SHENNAI brand melting furnace, so as to prepare the molt to be poured into the ceramic cast. The natural cooling rate of the internal slabs of the mold of melted recycled aluminum cans is to be monitored on-time schedule via type RS Pro Type J thermocouples; 0.3 mm diameter and maximum temperature sensed +750°C, that are protected in a stainless steel sheath (figure 1), distributed between the center and the edges. These thermocouples are linked with a computerized data acquisition system. The MATLAB software is used to handle the recorded data and apply the artificial neural network technique in order to recognize patterns and formalize the temperature changes along with the time. The linear vertical cutting machine is to be used in order to obtain samples that are transversely cut of ingots in the study area. The samples are to be polished and etched by Dix–Keller reagent so as to be ready for further tests. optical emission spectrometry would serve for the study of the chemical compositions of all ingots, via the use of the SPECTROPORT mobile metal analyzer by SPECTRO Analytical Instruments, Inc. (figure 2), in order to correct the microstructure and the parameters of the thermal analysis.
The use of the MATLAB approach in order to develop ANN for the case under study is step by step demonstrated by figure 3 during which, the data are read from the Excel file that is made by the linked computer system.

**Figure 1.** RS Pro Type J Thermocouple.

**Figure 2.** The SPEXTROPORT mobile metal analyzer by SPECTRO Analytical Instruments, Inc.

**Figure 3.** Step by step flow chart for the ANN model using MATLAB.
3. Results and discussions
The simultaneous reading of all thermocouples that are distributed on the edges and center of the recycled aluminum cast are averaged and illustrated by figure 4. The two lines show that the temperature drops acutely for during the first 40 seconds, subsequently, this drop tends to moderate during the following 80 seconds and tends to settle afterward until the complete solidification (liquid-solid) occurs after about 155 seconds from the start point; from 689°C to 500°C. It is obvious here that the cooling and hence the solidification processes occur at the edges of the cast in slightly quicker manner than the center, especially after the lapse of about 40 seconds where the two curves show obvious separation.

![Figure 4. Temperature drop with time in cooling recycled aluminum cast.](image)

The program that was designed via the utilization of MATLAB is the study mean in order to determine the relationship between the two understudy locations (center and edges) lengthwise the drawn cooling curves based on the time-temperature data. ANN technique was approached in order to formalize the mathematical relations that define the time tendency of the cooling rates for the center and edges of the cast as tabulated in table 2. The first remark from table 1 is the high correlation between the cooling rate and the time through the natural solidification process that took around 3 minutes until solid casting could be visualized in the mold. The results demonstrate that the cooling process at the cast edges proceeds slightly faster than that at the center because of the multi-dimensional heat flow pathways that are available for the edges while the center of the cast has less heat flow pathways. The important remark drawn from the application of the ANN technique that considers the interior layers through the aluminum cast is the more accurate cooling rate determination formula that is not so clear via the information that may be based on the cooling curves shown in figure 4 that are based on the records of the spot thermocouples.

| Location | Equation | R² |
|----------|----------|----|
| Center   | Cooling rate = -0.145* time + 29.40 | 0.95 |
| Edges    | Cooling rate = -0.132* time + 40.60 | 0.97 |

Table 2. The output of MATLAB using ANN for the cooling rate determination.
the grain size. Figure 6 illustrates the microstructure of the edge sample that illustrates the faster solidification of edge locations as compared to that was shown by figure 4 for the center of the casting. Also, many additional compounds might be considered as effective in the casting structure; intermetallic phase particles besides the oxides.

Figure 5. the casting microstructure at the center of the casting.

Figure 6. the casting microstructure at the edge of the casting.

4. Conclusions
The utilization of the ANN technique as a tool for the tracking of the solidification process through the slab layers of a cooling cast of recycled aluminum was tested by the use of the ANN technique. The laboratory handled aluminum cans were collected and prepared to make the proper mold to be poured into a ceramic cast. The reading of thermocouples that were distributed on the edges and the center of the casting were recorded by a computer system in an excel sheet so as to act as an input for the determination of the mathematical formulas via MATLAB, that describe the natural cooling process’s trend and its time dependence. The outcome of these mathematical relations shows that the edges have shown a faster cooling rate as compared to that of the center of the casting, and this was visually illustrated by the microstructural photos of the vertically cut slabs of the casting that was made by the SPECTROPORT mobile metal analyzer.

5. References
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