Optimization of electromagnetic systems of impact on metals in semi-solid casting condition

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Abstract. The paper studies the electromagnetic technology for the manufacturing of the ultralight panels on the basis of the foamed aluminum. The requirements for the temperature gradient for foamed aluminum production are shown. The determining factor when choosing the heating mode is the billet heating quality criterion. The key parameters ensuring its optimum value are the choice of the load heating mode, the billet travel speed, and the frequency value. The travel amplitude of the reciprocating movement was selected on the basis of the famous theoretical and practical experience of heating in this mode. The frequency selection is affected by several parameters, namely: inductor efficiency, voltage and current, reactive power.

1. Introduction

This paper shows the findings on the electromagnetic production technology of ultralight panels, manufactured on the basis of the foamed aluminum materials, possessing the unique technological and performance characteristics: low thermal conductivity, high corrosion resistance, and high modulus of elasticity. All the above allows considering the foamed aluminum panels as prospective structural material for mechanical engineering, shipbuilding, construction and other industrial sectors. E.g. the use of foamed aluminum in industrial building and civil construction ensures fire safety, heat- and sound absorption, environmental safety, light weight and the structurally attractive suitability for the use as interior finishing; in energy sector, thanks to its screening capacity, it ensures the absorption of electromagnetic emission from large and small electrical substations, electrical installations and radiators; in mechanical engineering it ensures vibration insulation and vibration damping, as a filler (for ensuring construction rigidity), as well as using as noise, vibration and heat insulating material, and impact dissipation device, because its strength exceeds the strength of the conventional metal several times; in automobile industry it resolves issues of improving passenger safety at the expense of the installation of energy absorbing inserts and automobile weight reduction when using the sandwich structural parts manufactured of foamed aluminum; in the field of the new materials creation it ensures the substantial improvement of the heat and sound absorption efficiency, as well as the electromagnetic emission absorption increase with the preserving of the environmental safety.

2. The certain processing requirements for the materials, manufactured on the basis of the foamed aluminum ultralight panels

This paper shows the findings on the electromagnetic production technology of ultralight panels, manufactured on the basis of the foamed aluminum materials, possessing the unique technological and
performance characteristics: low thermal conductivity, high corrosion resistance, and high modulus of elasticity. All the mentioned above allows considering the foamed aluminum panels as prospective structural material for mechanical engineering, shipbuilding, construction and other industrial sectors. For example, the use of foamed aluminum in industrial building and civil construction ensures fire safety, heat- and sound absorption, environmental safety, light weight and the structurally attractive suitability for the use as interior finishing; in energy sector, thanks to its screening capacity, it ensures the absorption of electromagnetic emission from large and small electrical substations, electrical installations and radiators; in mechanical engineering it ensures vibration insulation and vibration damping, as a filler (for ensuring construction rigidity), as well as using as noise, vibration and heat insulating material, and impact dissipation device, because its strength several times exceeds the strength of the conventional metal; in automobile industry it resolve issues of improving passenger safety at the expense of the installation of energy absorbing inserts and automobile weight reduction when using the sandwich structural parts manufactured of foamed aluminum; in the field of the new materials creation it ensures the substantial improvement of the heat and sound absorption efficiency, as well as the electromagnetic emission absorption increase with the retention of the environmental safety [1].

The foamed aluminum sandwich panels consist of two external sheets of solid metal and the metal core inside, manufactured of the foamed aluminum alloy. Fig. 1 shows the appearance of the simplest finished (sandwich) panel on the basis of the aluminum alloy after foaming.

![Figure 1. Foamed aluminum's Sandwich; 1 - cast framework; 2 - made foam part](image)

For the required physical-mechanical properties of the materials, manufactured on the basis of the foamed aluminum ultralight panels, the certain processing requirements are specified, including the thermal treatment requirements.

The studied production technology of ultralight panels, manufactured on the basis of the foamed aluminum materials, consists of the following principal stages:

- powdery raw material loading;
- batch preparation and container formation;
- compaction (consolidation) by hot rolling;
- billet-precursor foaming;
- end product acquisition.

During the production process, the aluminum alloy powders [1], [2] after mixing with a small amount of the foaming material (titanium hydride) are put into the flat steel of aluminum container, ensuring the specified precursor geometrical dimensions and the final sandwich panel formation. This should be taken into account when designing the induction furnace, used for heating the container with the aluminum alloy powder in the periodic or continuous mode up to 400 – 550 °C for the subsequent hot rolling and acquisition of the compacted intermediate plain product (precursor).
3. **Researches on the electromagnetic production technology of ultralight panels, manufactured on the basis of the foamed aluminum materials**

In the course of the study, the two possible heating modes of the load were considered: static and periodic with the reciprocating movement. The continuous mode wasn’t considered because it was essential to simultaneously heat the load up to the predetermined temperature along the full length of the load.

Each method had its advantages and disadvantages. Thus the static mode has the higher efficiency and subsequently requires less heating time, but at the same time it has many substantial defects: poor heating of the billet butts, an area with the temperature, fall outside the required temperature limits, which can make up to one-third of the load length (see fig. 2). This makes this method extremely disadvantageous for use at works. It also should be noted, that for good temperature uniformity at the central part of the load, the inductors should be arranged immediately adjacent to each other, which complicates the billet loading and unloading process.

![Figure 2. Temperature distribution at billet-precursor length during static heating mode](image)

The heating in the periodic mode with reciprocating movement is inferior to the stationary mode in terms of efficiency and the heating time but permits the several times decrease of the area of poor heating at the billet butts (fig. 3). With the same level of load central part temperature irregularity, it also permits arranging the inductors in spaced relationship, facilitating the process of designing the billet loading and unloading system.

The determining factor in the selection of the heating mode was the criterion of the billet heating quality, i.e. the best temperature uniformity over the billet length. Hereby the periodic mode with the reciprocating movement was selected for billet heating [3], [4].

As a result of the study, it was found out that at the specified power of 400 kW the provision of the precursor fast heating is only possible at the precursor thickness range from 4 to 7 mm. In the case of the thicker load, the specified power is insufficient for fast heating because of the load mass, while the thinner load becomes transparent to the electromagnetic field and cannot heat up to the required temperature at the specified power.

The travel amplitude at the reciprocating movement was chosen proceeding from the available theoretical and practical experience of heating in this mode [5], [6]. Whence it follows that the travel...
amplitude should be a multiple of the sum of the inductor width and the gap width between the inductors, i.e., in this case, it is 750 mm.

\[ T, ^\circ \text{C} \]

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Temperature distribution at billet-precursor length during periodic heating mode with reciprocating movement}
\end{figure}

The frequency selection is affected by several parameters [7], namely: inductor efficiency, voltage and current, reactive power. The optimum alternative is the use of the 8 – 10 kHz frequency. It permits getting the acceptable values of current and voltage on the inductor for plant manufacturing. For higher frequencies, the reduction of the plant efficiency and the increase of the inductor current occur. At the frequency of 30 – 100 kHz, the significant increase of current on the inductor and the decrease of \( \cos \varphi \) at the insignificant decrease of inductor current occur.

The billet travel speed directly affects the thermal gradient over the length of the load [8], [9]. At the smaller speeds, the irregularity of heating is rather high, because at the speed of 0.03 m/s, it is 100 – 120 \( ^\circ \text{C} \), and at the speed increase, the irregularity of heating decreases. Thus, at the 0.05 m/s, it is already 22 – 28 \( ^\circ \text{C} \), and with the subsequent speed increase, there are no significant changes in the thermal gradient over the length of the billet. It also should be noted that the speed increase may lead to the billet slippage at the moment of changing the direction of movement, therefore the speed decrease whenever appropriate is required.

When heating the billet its nonuniform heating is observed (fig. 3). At the same time the several types of nonuniform heating, provoking thermal gradients, can be marked out:

Over the length of the billet regular part, i.e. the billet central part, this area composes the largest part of the billet. The thermal gradient value can be controlled by changing the billet travel speed.

Over the billet width, as can be seen in fig. 3, it follows the thermal gradient profile at the billet regular part and depends on the heated billet thickness. At the same time, with the thickness of under 10 mm, the underheating of the billet side edges, and with the greater thickness – the overheating is observed.

At the billet butts, which is due to the edge effect of the induction heating. This thermal gradient is the highest and falls beyond the scope of the allowed temperature range. To control the thermal gradient the change of power on the extreme inductors is required. Because all the 8 inductors are
connected to one power source in parallel, the change of the output power on the inductor is possible at the expense of the number of the coils changing.

Fig. 4 shows the temperature maximum deviation as a function of the specified range and the length of the butt area having this temperature deviation as a function of the precursor thickness for the occurrences, when all inductors are identical, when the extreme inductors are 1 coil greater and when the extreme inductors are higher.

![Figure 4](image)

**Figure 4.** The graph of the maximum temperature deviation as a function of the precursor thickness: 1 - identical inductors; 2- extreme inductors with 6 coils; 3- extreme inductors are 95 mm in height; 4 - extreme inductors are 100 mm in height

As can be seen from the graphs, in our case the controlling of the heating quality by means of the number of the coils changing is very rough because of the low number of the coils.

4. **Conclusion**

The change of the height of the extreme inductors provides the much better control, which permits decreasing both the temperature deviation value from the specified range and the butt area width with temperature deviation. But nevertheless, it is unable to provide the required heating quality over the whole billet assortment. In the case of identical inductors and when the extreme inductors have the greater height, the overheating of the butt area occurs, and in cases where the extreme inductors are 1 coil greater, the butt area is not heated up to the required temperature.

On the basis of the undertaken studies, the induction equipment for high-temperature electromagnetic treatment of the large-sized flat articles on the basis of the aluminum alloys in the induction furnace was developed.

**Acknowledgments**
The research, about which the report was conducted, is within the federal target program "Scientific and Research and Educational Personnel of Innovative Russia" for 2009-2013 for a subject: "Development of innovative technologies of processing of metals in a semi-solid casting condition state for space branch". The state contract of December "1", 2010 No. 14.740.11.0824
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