Physical Modelling of the Corona Discharge Effect on the Casting in the Mold

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Abstract. In this article we describe the technique and the methods of physical modelling of the corona discharge usage in order to harden the material. The active substance in the detector is the liquid crystals of a cholesteric type with a mesophase of 40–45 °C. The substrate of the detector is a cast of aluminum alloy with specified parameters in the form of a rectangular or round shape. A corona discharge is created with the help of high-voltage power source (e.g. «Разряд») when the voltage is applied to a pair of needle-plane electrodes. The modulation of the ultrasonic signal is carried out through the inductive coupling. The parameters of the corona discharge are calculated with accordance to the received samples and temperature patterns. An assessment of the effect of a corona discharge on a liquid metal is determined by the Brinell scale displaying the indentation hardness.

1. Introduction
A corona discharge is a specific form of an independent gas discharge brought on by the ionization of a fluid. The main feature of this discharge is that ionization processes by the electrons do not occur along the continuity length but in its smallest part close to the electrode with a small radius of curvature (known as corona electrode). This part has significantly higher field strength compared to the rest of the continuity length. It is caused by relatively high pressure (almost at the level of atmospheric pressure) in the non-uniform electric field. Similar fields are formed at electrodes with a very large curvature surface (tips, thin wires). When the field strength reaches the limit value for air (about 30 kV/cm), a glow appears around the electrode in the form of a shell or corona (hence the term)[1,2].

2. The main part
To determine the parameters of the corona discharge in the needle – layer system [2], we propose to use a liquid crystal detector. This device is a combination of flat electrode 1, one side of which is blackened and covered with thermotropic liquid crystals 2. The second electrode is a needle 3. The electrodes are installed at an assigned distance with a high voltage of about 20-25 kV being applied to them (Fig. 1).
Figure 1. The corona discharge detector: 1. Flat electrode. 2. Layer one side of which is blackened and covered with thermotropic liquid crystals. 3. The needle electrode.

It must also be considered that the corona discharge can be positive at the positive value of the anode (+) and negative at the negative value of the anode (-). This fact is easily verified with the help of a liquid crystal detector. Fig. 2 shows the effect of the positive and negative corona on the liquid crystal film with a constant distance between the electrodes and the constant voltage applied to them.

Figure 2. The effect of the corona discharge upon the liquid crystals detector: a – the surface of the positive corona discharge impact. b – the surface of the negative corona discharge impact. With a constant distance between the electrodes and the constant voltage applied to them.

In this case, the diameter of the positive corona is 4.5 mm larger than the diameter of the spot of the negative corona. This feature of the corona discharge must be taken into an account when processing the results of the experiment especially when the gradation scale of the spot is counted in kV/mm. For example, on the Fig.2 we can see pictures a and b with different gradation scale. Within the corona discharge, the density distribution of the electric charge flow is spread from the center, created by the copper electrode 3, to the edge. Fig. 3 shows a coloured picture of the corona discharge temperature field, received with the help of liquid crystal detector 2 on the Fig.1. The mesophase of the liquid crystal detector during its use is between 40-45 ° С. The ultraviolet part at number 5 in the center of the figure is at 45 ° C, the red part at number 6 closer to the edges is 40 ° C, other colours are present according to the spectrum of visible light. Colours, showing the temperature, are meant to reflect the density of the charged particles flow and they are presented in the form of concentric circles - isotherms - starting from the center of the corona discharge spot.
By determining the gradation scale of the number 4 spot diameter, in this case, we can count the voltage parameters for each isotherm, assuming the equality of the amount of heat, measured through the current and temperature [3].

Now we want to consider the possibility of corona discharge application with ultrasonic vibrations within their exposure to liquid metals. If we direct ultrasonic vibrations within the range of 18 KHz to 2.5 MHz to the liquid metals, it is possible to control the crystallization process [4, 5]. One of the issues in this case is the way the ultrasonic wave enters the container with liquid metal. There are several methods of appropriate concentrators usage for ultrasonic vibrations: direct entry through the pipe into the melting pot or indirect – through the wall of the mold [1]. Special industrial generators have been created in order to do that. All these liquid metal manipulation methods have their positive and negative implementation aspects.

With an indirect method of influencing a liquid metal, an ultrasonic wave passes from the emitter through the interface into the liquid metal. At the same time, significant signal power losses are observed at the interface, which imposes certain conditions on the signal level. Thus, an ultrasonic emitter entering the melt of the waveguide is only possible with a limited exposure time. However, the influence of ultrasonic vibrations on a liquid metal through a coronary discharge avoids listed above disadvantages and is carried out according to the scheme in Fig. 4.

Figure 3. The corona discharge temperature field: 1. Sample. 2. The liquid crystals layer. 3. The copper electrode. 4. The diameter of the corona discharge spot. 5. The center of the corona sport. 6. The border between irradiated and non-irradiated crystals.

Figure 4. The scheme for implementing ultrasonic vibrations into the aluminum melt: 1. The mold with the liquid metal. 2. The needle electrode. 3. Modulator. 4. Voltage converter. 5. Ultrasound generator.
The molten aluminum prepared in a muffle furnace is poured into the mold 1 (Fig. 4). Upon completion of the casting, a 25 kV corona discharge and an ultrasonic oscillation generator are switched on. The required exposure time of the corona field lasts about 10 seconds. Two castings from the same series of aluminum smelting are cast. One casting is exposed to a corona discharge, the other is not irradiated, samples are labeled and tested. This allows us to further compare the results of the experiment. Assessment of the effect of corona discharge on a liquid metal was determined by the Brinell scale displaying the indentation hardness. The results allow us to conclude that the hardness of the aluminum alloy varies in the surface layer by about 1.37 times with respect to the mold untreated by the corona discharge, and the surface hardness and hardness at a depth of 4 mm differ by 2.04 times.

3. Conclusion
We can conclude that, based on the analysis of the two sampled molds, there is some non-uniformity in the distribution of surface hardness. The sample without corona discharge application has more uniform hardness as oppose to the second sample with corona discharge application, and the differences between their hardness numerical ranges are present in almost doubled amount (~ 2).

There are several possible reasons for that:
1) Non-uniformity of the corona discharge electric field during the application to the surface of the sample;
2) The electrode shape;
3) The distance between electrodes;
4) The corona polarity;
5) The corona temperature;
6) The valve material.

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