APPLICATION OF HEAT PIPES AS A TECHNOLOGICAL EQUIPMENT

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Abstract

In the present paper the application in technological units of cooling systems based on heat pipes have been considered. This equipment allows to produce materials with improved mechanical and physical properties. The analysis of the application of heat pipes shows their advantages compared to the common cooling systems.

KEYWORDS

heat pipe, rapid solidification, impact atomization, wire patenting

INTRODUCTION

Nowadays **R**apid **S**olidification **P**rocesses (RSP) are widely used to manufacture new materials that can not be produce by traditional casting methods. These materials are characterized with extended solid solubility, formation of new nonequilibrium phases or even the amorphous state. All these feature are the result of the rapid quenching from the liquid state.

The cooling rate in RSP usually exceeds 10^3K/s. To achieved such level of cooling rates it is necessary to provide the sufficient heat extraction from the melt. It means that the cooling systems in RSP play the important role. One of the promising way to develop the effective technological equipment for RSP is the application of heat pipes in cooling systems.

THE DIRECT PROCESS TO PRODUCE THE WIRE OF SMALL DIAMETERS

The common technology to produce small wires includes multistage billet's drawing. Due to this feature the process to manufacture wires with small diameters is rather expensive. Moreover the working life of drawing dies is still not sufficient. One of the way to decrease the cost of the process is the reduction of the initial billet's give. The rotating casting wheel is more suitable to organize the continuos casting process of near-net shape billets. On the other hand the effectiveness of this equipment depends on the cooling system applied.

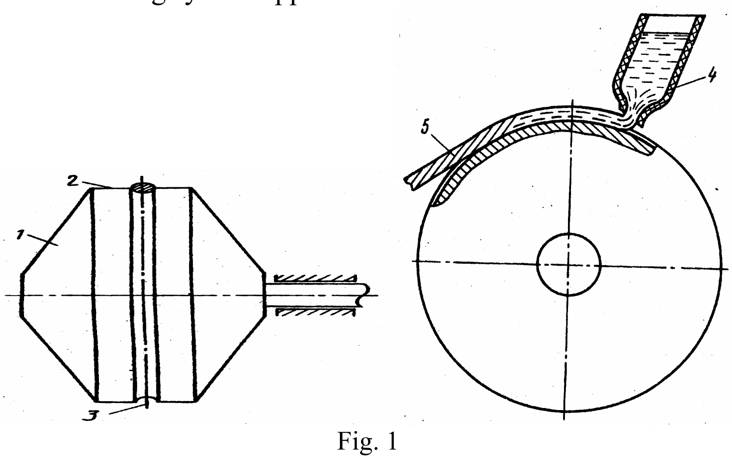

Fig. 1
1 – heat pipe, 2 – non-wetting surface, 3 – groove, 4 – tundish, 5 – wire

We offer the casting machine with the cooling system based on the centrifugal heat pipe [1]. It's more exactly to say that the heat pipe serves as a casting machine. The outer (working) surface has the profiled shape (Fig. 1). The groove surface is made of the material that can be wetted by the melt. The rest of the surface is not welted by the melt. The different wetting properties of the outer surface provide the formation in groove of the round billet's cross-section. The melt in the groove is kept by the surface tension due to the wetting. Let's consider forces that act on the solidifying melt.

The capillary pressure that keeps the melt in the groove can be written as:

$$P_c = \frac{\sigma}{R_p}\cos\theta \tag{1}$$

The centrifugal pressure that tries to remove the melt from the wheel surface:

$$P_{cf} = 4\pi^2 n^2 R_{wh}\rho_m R_p \tag{2}$$

One can obtain the equation to calculate the wire diameter from (1) and (2) depending on the wheel revolving velocity:

$$R_p = \frac{1}{2\pi n}\sqrt{\frac{\sigma\cos\theta}{\rho_m R_{wh}}} \tag{3}$$

From (3) it is possible to predict the wire diameter depending on the melt properties revolving velocity and the wheel diameter.

The wire diameter produced with this unit is in the range from 1 to 3 mm. So, it is one application of the heat pipe as a technological equipment.

THE APPLICATION OF HEAT PIPERS FOR THE PATENTING OF A STEEL WIRE

During the production the steel wire is treated by special thermomechanical process, so called "Patenting" to achieve the required properties. In this process the wire is heated to the temperature A_3 (920-930^{0}C) and then rapidly quenched (~1 s) up to 420^{0}C. At this temperature the wire is kept at least 15 s.

At present he lead bathes are used for the patenting process. It is attractive to avoid the application of lead bathes due to ecological problems.

We offer the solution of this problem. Firstly, the process is divided in two independent stages [2]. Moreover different equipment is used in the each stage. The process described above to produce the wire can be used in the first stage. The wire from the casting machine is cooled by the art to the temperature A3 and then rapidly quenched by the heat pipe. The wire moves along the evaporator surface and can be quenched with the certain cooling rates. The last depends on the heat extracting intensity determined by the coolant rate through the condenser of the heat pipe.

The isothermal treatment is performed with the heat pipe which can heat the wire aiming the maintenance of the certain temperature. Cylindrical heat pipes were made of copper M2 with outer diameter 0.3 m and inner one – 0.28 m. The capillary porous layer made of sintered copper particles ∅ 1-1.2 mm with the thickness 3 mm was deposited onto the inner pipe's surface. The heat pipe was filled with heat carrier – dipfenil mixture. The compressed air was used as a cooling medium. The temperature of the pipe's wall reaches 400 ^{o}C. The roller for the isothermal treatment had the length of the working area 100 mm and the length of the heated part – 250 mm. The heater in the roller for the isothermal treatment was made of Ni-Cr steel wire with ∅ 0.3 mm. To keep the required temperature it's necessary to control the capacity of the electric heater in the heat pipe.

The contact time between the wire and heat pipes is determined by the treated steel and controlled by the number of the technological line is showing in Fig. 2.

So, the process offered is characterized with a higher productivity and better ecological influence on the environment.

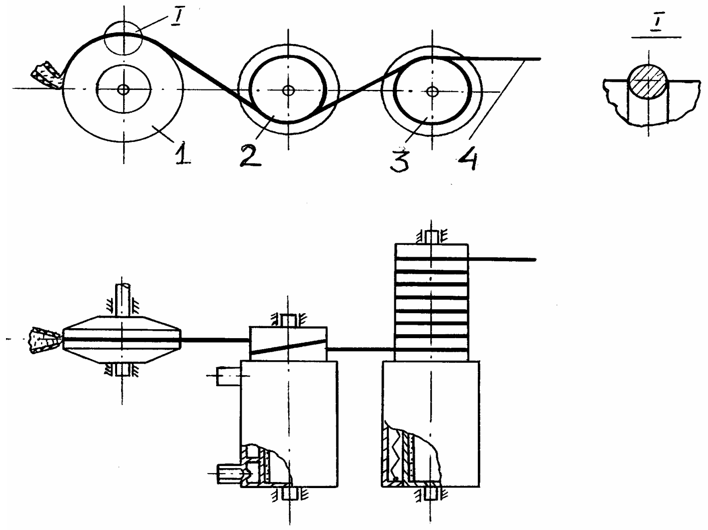

Fig. 2. 1 – wire casting, 2 – wire quenching, 3 – wire annealing, 4 – ready wire.

THE APPLICATION OF THE CENTRIFUGAL POPOUS EVAPORATOR
TO CAST THIN RIBBONS

The majority of casting wheel machine to produce ribbon apply the cooling system on the connective principle. In this case a fast moving coolant extracts the heat from the casting wheel. But due to nouniformity of the heat exchange conditions one can observe the local boiling of a coolant resulting in more worse quality of ribbons casted. To provide more stable and uniform cooling conditions it is promising to use a centrifugal porous evaporator as a casting wheel [3]. A drawing of the continuous casting unit to produce thin ribbon is shown in Fig. 3. A porous layer is cladding into inner (non-working) surface of the wheel. Moreover, the unit is equipped with porous bodies in the central (axis) part to control the coolant rate. Under the centrifugal forces the coolant moves through porous bodies (Fig. 3) towards a porous inner surface of the wheel. Due to the surface tension the cooling liquid distribute uniformly on the inner wheel surface. The coolant extracts the heat from the wheel due to the evaporation process.

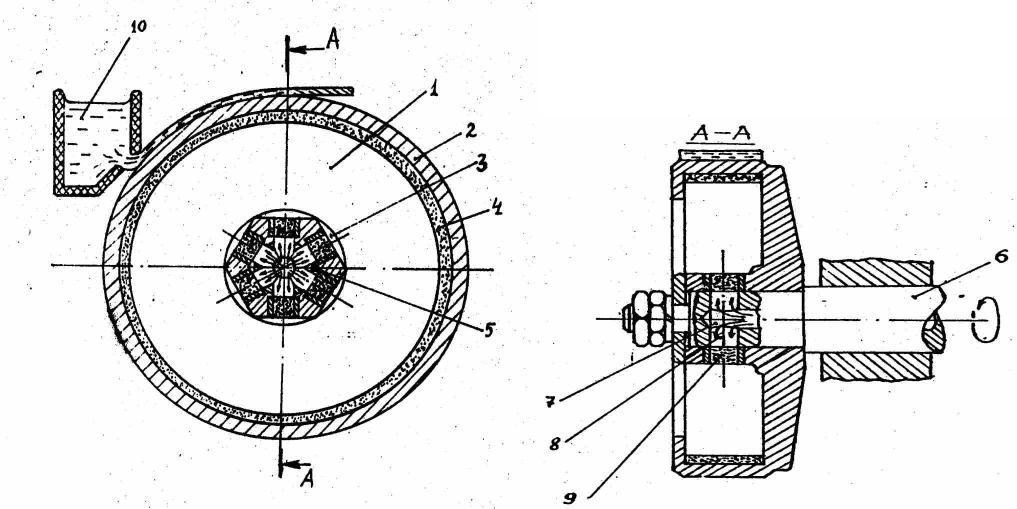

Fig. 3 1 – casting machine, 2 – rim, 3 – hub, 4 – porous layer, 5 – pin,
6 – axis, 7 – internal hole, 8 – radial holes, 9 – porous body, 10 – tundish.

It is known that the mass rate of the liquid passing through the porous bodies can be determined from the equation:

$$m = \frac{A \cdot P \cdot Pm \cdot \rho}{\mu L}$$

The permeability passing throug of the porous body characterizes the square of it's free cross-section and the resistance to the h the resistance to the passing through liquid. It is determined by the particle's size and their volume shave. The required mass rate can be determined as:

$$m = \frac{c_p(T_m - T_{rib})M}{r^*}$$

The pressure to move the liquid through the porous body can be determined as:

$$P = 4\pi^2 n^2 R_{ml} \cdot l \cdot \rho_i$$

So, changing the porous baby's permeability, its geometrical sizes and number one can provide the certain liquid coolant's rate. The porous body can be replaced depending on the machine revolving velocity, king of melts. The liquid coolant spreads along the inner-surface of the wee due to the surface tension.

The manufactured unit had the outer diameter of the pipe 0.3 m and the inner one- 0.275 m with the width 0.05m. the diameter of the hole axis was 0.05 m. The axis has 6 holes with ∅ 0.018 m of each. 6 porous bushes had the ∅ 0.018 m and the height 0.018 m. Porous layer with the thickness 2 mm was deposited onto the inner surface of the pipe and made of copper spherical particles of ∅ 1.0 mm.

The unit was tested at 4 revolving velocities: 25, 50, 75 and 100 s^{-1}. The productivity rate was 1.4 kg/s for all runs. The thickness of ribbons was 0.3, 0.15, 0.01 and 0.08 mm correspondingly. The total head capacity removed from the pipe-wheel was 933 kW. To provide the effective cooling it was necessary to keep water rate equal to 0.07 kg/s through each porous bush. The permeability of the bushes must be $\Pi = 1.25 \cdot 10^{-3}$, $3.14 \cdot 10^{-4}$, $1.38 \cdot 10^{-4}$, $8.0 \cdot 10^{-5}$ m^2. The sizes of spherical particles used to sinter bushes were 1.2, 0.6, 0.4 and 0.1 mm.

So, the centrifugal porous evaporator provides the uniform heat extraction from the wheel and monument liquid coolant's consumption.

THE HEAT PIPE AS A UNIT FOR THE IMPACT ATOMIZATION

The unit of the impact atomization consists of the heat pipe with the profiled outer surface [4]. The teeth of the profiled surface destroy and atomize the melt jet. Due to the surface tension the liquid particles after the impact transform into spheres. The heat pipe serves as a thermal controller that provides the certain rate of the cooling liquid by the change of the spiral pump productivity. The coolant maintain the fixed teeth temperature. This teeth temperature must be high enough to avoid the melt solidification on the tooth surface but to extract a certain amount of the heat aiming the particles solidification before the container.

Nomenclature

A – square, m^2; c_p – heat capacity, J/(kg·K); k – coefficient; l – drilling length, m; R – length of the porous body's capillary, m; m – melt; M – productivity, kg/s; n – revolving velocity of the machine, s^{-1}; P – pressure, Pa; P_c – capillary pressure, Pa; P_{cf} – centrifugal pressure, Pa; R_{wh} – casting wheel radius, m; R_p - groove radius, m; r* - latent boiling heat, J/kg; T_m – pouring melt temperature, K; T_{ex} – outlet wire temperature. K; Π – permeability, m^2; θ - wetting angle, μ - viscosity, N·s/m^2; ρ - density, kg/m^3.

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